

**KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,
KUMASI, GHANA**

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Impact of Industrial Effluents on the Quality of Onukpawahe Stream, Tema

By

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College of Engineering

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Water Resource Engineering and Management

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DECLARATION

I hereby declare that this thesis is my own work towards the Master of Science (MSc) degree in Water Resource Engineering and Management and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

I dedicate this work to my parents and my wife for their continuous support during my study.

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My profound gratitude goes to the Almighty Allah for the wealth of His grace, mercy, guidance, strength, protection, steadfast love and wisdom throughout the program.

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ABSTRACT

Industrial effluents discharge into surface water body represents a high source of pollution in Ghanaian streams and rivers. They impact on the water quality, the microbial and aquatic flora. The current study was carried out to determine impact of industrial effluent on the quality of Onukpawahe Stream which receives industrial effluents as point sources in the Tema Motorway industrial area in the Tema Metropolis. Effluent samples were collected from six (6) selected industries and the water samples collected from sixteen (16) different locations on the Onukpawahe stream. Various physico-chemical parameters such as Biological oxygen Demand (BOD), Total Dissolved solids (TDS), Conductivity (EC), Chemical Oxygen Demand (COD), pH, Total Suspended Solids (TSS), Turbidity, Temperature, Colour, Sulphate, Phosphate, Ammonia and Nitrate and heavy metals (Copper (Cu), Zinc (Zn), Cadmium (Cd), Lead (Pb), Chromium (Cr) and Iron (Fe) were analysed during the current investigation. The average values of all physico-chemical parameters (except pH and DO) were above the EPA guideline values and metals were considerably higher in the industrial effluent and downstream than upstream while effluent discharge point showed the highest values for all sampling sites. The lowest values for pH and DO were also recorded at effluent discharge point and concentrations of iron (Fe) downstream exceeded acceptable limits for surface waters. It was established in the study that the industries have polluted the stream and resulted in the poor quality of the Onukpawahe stream. Sources of water pollution include effluents from Abattoir (slaughter House) industry (high nitrate, chromium, BOD), food and beverage manufacturing industry (high pH, EC, TSS), Textile industry (high Pb, Colour and Cadmium, COD) and food processing industry (high EC and BOD). As a result, the quality of the whole stream according to the CCME Water Quality Index (CCME WQI) is classified as poor. The surface water and industrial effluent must be monitored on a continuous basis and the findings of this study should be useful for implementing pollution management strategies in the catchment area of the Onukpawahe Stream.

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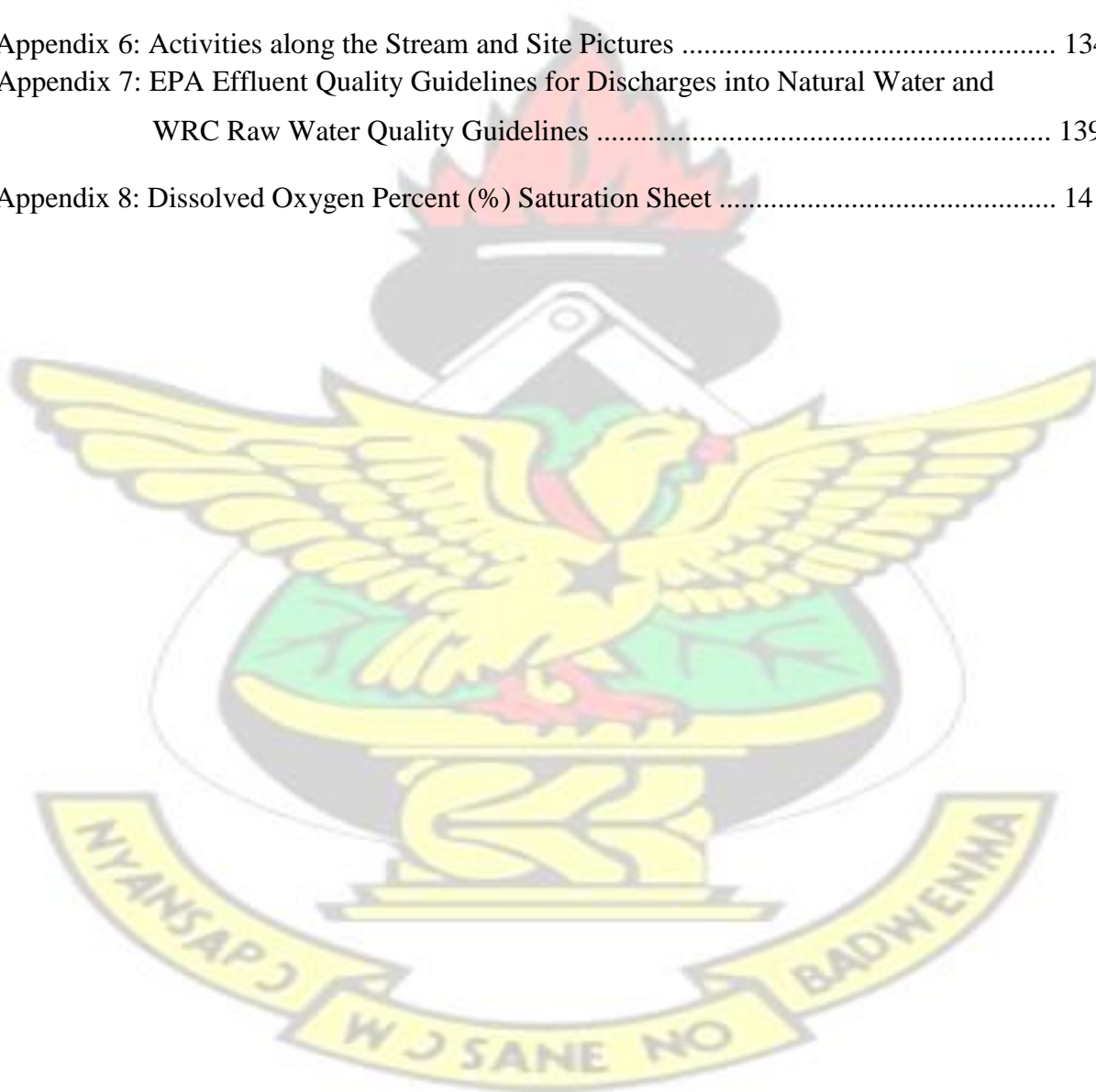
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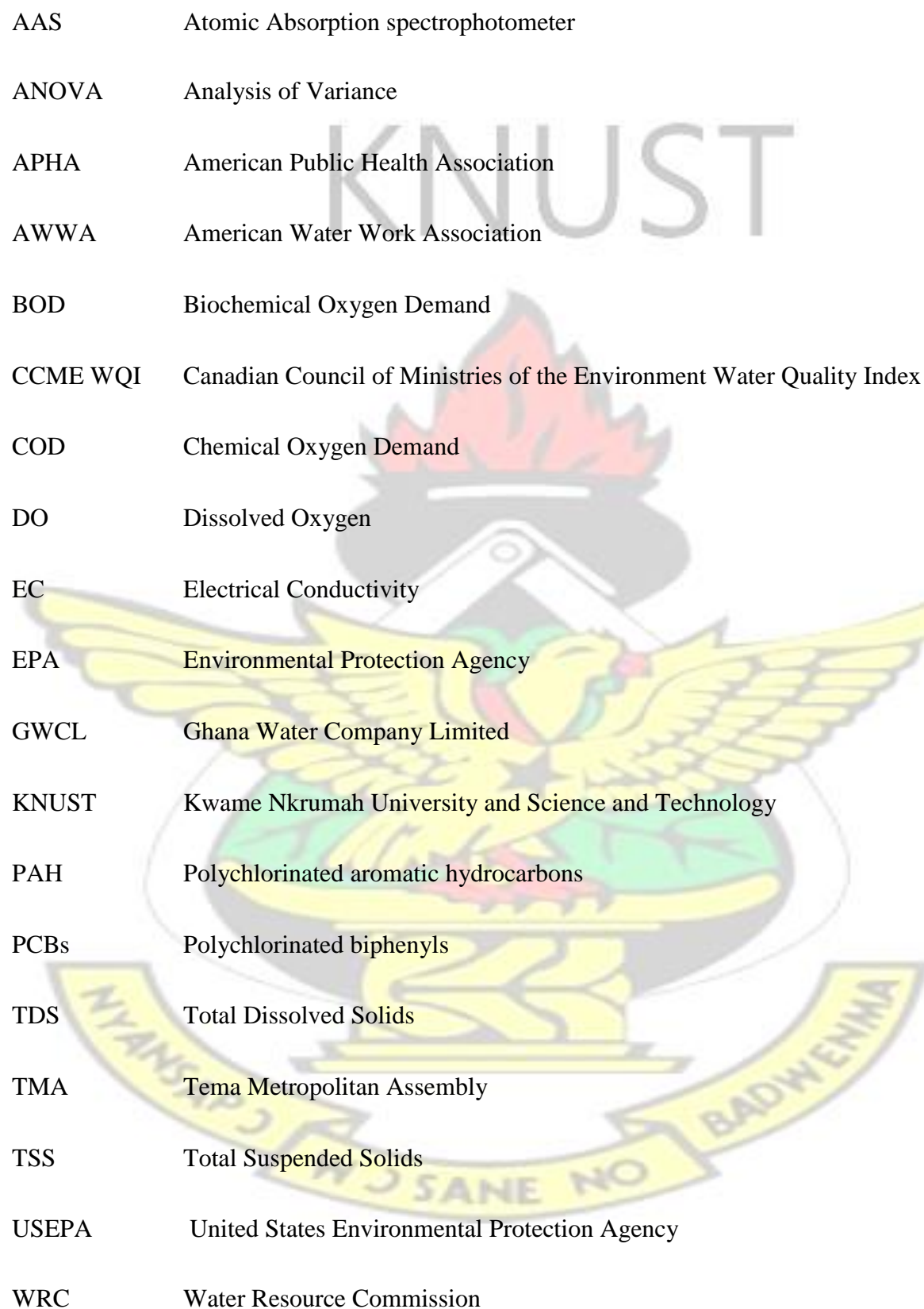
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LIST OF ACRONYMS



AAS	Atomic Absorption spectrophotometer
ANOVA	Analysis of Variance
APHA	American Public Health Association
AWWA	American Water Work Association
BOD	Biochemical Oxygen Demand
CCME WQI	Canadian Council of Ministries of the Environment Water Quality Index
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical Conductivity
EPA	Environmental Protection Agency
GWCL	Ghana Water Company Limited
KNUST	Kwame Nkrumah University and Science and Technology
PAH	Polychlorinated aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
TDS	Total Dissolved Solids
TMA	Tema Metropolitan Assembly
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
WRC	Water Resource Commission

CHAPTER 1: INTRODUCTION

1.1 Background

The rapid growth in population, industrialization and the accompanying technology involve waste discharges, the rate at which these pollutants are discharged into surface waters is far greater than the carrying capacities of these water bodies (Shivayogimath *et al.*, 2012). In Ghana, the main source of contamination of streams is the discharge of domestic wastewater from urban and town centers and industrial effluent which bring about water borne diseases. The cases of cholera outbreak in Accra and other cities in Ghana are clear examples. Assessing the quality of water is important for controlling contamination and the preservation of streams and rivers. According to Bartram and Ballance (1996) as the population of man increases at faster rate in the previous century which leads to increase in the demand for water the most essential commodity on the earth, are increasingly pressurized and continually polluting the water bodies by agricultural, household waste and industrial effluents.

Onukpawahe is a stream which lies between longitude 5° 39'24" to 5° 39'35" N and latitude 0°5' 22" to 0°3'20" W, the stream receives indiscriminate effluent discharges from the heavily industrialized and parts of the highly populated Accra and Tema Metropolis.

However, a number of water quality assessment in terms of various physico-chemical , biological characteristics and heavy metals of surface water at various places in the Tema Metropolis has been carried out (Agbemehia, 2013; Nartey *et al.*, 2012). The main goal of any water quality assessment or monitoring is to equalize the concerns of the consumers with the development of the resource, while enhancing and protecting environmental quality (Shivayogimath *et al.*, 2012).

Onukpawahe is an important stream of economic, agricultural and environmental importance in the Accra and Tema Metropolis. The stream receives industrial discharges from industrial facilities within the catchment of the stream. The stream also receives effluent from residential facilities and other anthropogenic activities occurring along its banks which also contribute to the pollution load. This edifies the importance of determining the effects of pollution on the stream and its aquatic organisms.

The quality of any stream or river is influenced by activities of man and natural sources (Okeola *et al.*, 2010). The main sources of water for industrial, agricultural and households purposes within the catchment of these water bodies are usually these streams (Phiri *et al.*, 2005). In related study by Koshy *et al.* (1999) reported that rivers or streams, though the most important water resources around the globe are contaminated by rampant and uncontrolled discharges of domestic effluent, industrial effluent and anthropogenic activities. The rate at which industrial effluent, agricultural waste and chemicals waste are disposed directly into the streams and river bodies have led to several degrees of effects on the aquatic life. The careless release of high amount of industrial wastewaters into surface waters result in the natural process of pathogen reduction being insufficient for protecting public health. Furthermore, industrial effluents discharges changes the water acidity or alkalinity which leads to high levels of bacterial nutrients which usually undermine the self purification capacity of the stream to trash microorganisms (Aboyeji, 2013). The rate at which industrial wastewaters are release into streams and rivers is such that water bodies into which these wastewaters are released can no longer undergo the natural self purification process as good quality water sources. Industrial effluent reveals different extent of environmental imbalance and degree of pollution load due to their chemical and microbial nature (Bernard, 2010). The consequences are high nutrient levels leading to dissolved oxygen depletion and release of harmful substances which include heavy metals that could bioaccumulate in microorganisms in the water (Morrison *et al.*, 2001).

Microorganisms in streams or river bodies have the capacity to accumulate pollutants such as heavy metals, Polycyclic Aromatic Hydrocarbons (PAH) and Polychlorinated Biphenyl (PCB) in the environments which are persistent organic pollutants (POPs). When these contaminants are taken into the body, it may impact not only on the productivity and procreative abilities of these microorganisms, but eventually impact on the health of human beings that depend on these organisms as a major source of food protein.

1.2 Problem statement

In the Tema Metropolis, the Onukpawahe stream is a major water supply source for farmers downstream. The water is perceived to be polluted by the discharge of effluent from surrounding industries. However, many people in the metropolis continue to use the polluted surface water in farming activities for cultivation of vegetables and other farm produce in the quest of meeting the growing demand for various kinds of vegetables in the urban areas. In response to EPA requirement for discharge into streams, some of the industries have installed wastewater treatment plants to reduce the pollution impact. However, most of these treatment facilities may not be meeting the Environmental Protection Agency's (EPA) effluent quality guidelines (EPA, 2012) leading to the pollution of the Onukpawahe stream and eventually resulting in the reduction in its carrying capacity thus allowing waste to seep into the Sakumono Lagoon.

1.3 Justification

There has been concern about proliferation of contaminated foodstuff such as fruits and vegetables in our local markets. According to a recent report, polluted water causes about seven hundred thousand (700000) deaths in Africa annually (GNA, 2008). Despite the socioeconomic importance of Onukpawahe stream there is lack of data and information on the quality of the stream and has necessitated for an in-depth assessment. To ensure a reliable and environmentally friendly industrialization in Ghana and the protection of our water resources, the determination

of the quality of streams and rivers is essential for controlling contamination and the preservation of our stream and river bodies. The findings from this work will generate information that could be used by regulatory bodies such as Environmental Protection Agency (EPA) and Water Resource Commission for enforcement of laws on pollution.

1.4 Objectives

The main objective of the current study is to determine the impact of industrial effluent on the quality of Onukpawahe Stream in Tema Metropolis.

The specific objectives are to;

- Conduct an inventory, map out and determine whether industries are meeting EPA effluent quality guidelines before discharge directly into the Onukpawahe stream.
- Determine the water quality (Physico-chemical, microbiological and heavy metals) at selected points on the stream.
- Determine the impact of industrial effluent discharges on the stream and propose possible mitigation measures.

1.5 Scope of Study

The study is limited to the Motorway Industrial Area in Tema and basically considers the impact of industrial effluent on the quality of Onukpawahe Stream by depending on the existing industries within the catchment of the stream.

1.6 Structure of the thesis

This thesis consists of five chapters. Chapter 1, made of the introduction, problem statement; justification; research objectives; and the scope of the study .Chapter 2 focuses on review of literature. Chapter 3 presents the general background of the study area and the research

methodology and explains how the study was carried out. Then Chapter 4 presents results and discusses the findings from the study .Finally, chapter 5 presents the conclusions and recommendations based on findings from the study.

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CHAPTER 2: LITERATURE REVIEW

2.1 Surface water resources in Ghana

The surface water basins in Ghana have been categorized into three systems (Sam-Okyere, 2015) as follows;

- Costal Basin System (Tordzie, Densu, Ayensu, Ochi- Nkwanta and Ochi- Amissah rivers).
- Southwestern basin system (Bia, Tano, Pra and Ankobra rivers).
- Volta Basin System (Daka, Oti, black and white Volta and the Lower Volta basin).

According to Sam-Okyere (2015), the water basins offload high amount of water into the sea every year without being tapped. Water bodies such as streams and rivers are potential sources of hydropower generation and reservoirs for agricultural activities.

2.2 Surface water pollution due to industrial activities

Natural water bodies such as streams, rivers, lakes, lagoons and oceans constitute surface water. Water pollution occurs when pollutants are introduced into water body and either mixed or dissolved in it (eschooltoday, 2016). The discharge of industrial wastewaters and other anthropogenic activities have polluted our water bodies which could be dangerous to aquatic life and pose health threat to man (Sam-Okyere, 2015). Small and middle scale factories are the common committers of this offence due to their inability to provide effluent treatment facilities for their wastewaters. They discharge their effluent directly into water bodies that traverse these areas. The residential facilities, with the exception of faecal matter, any other liquids waste are released into water system via the drainage system. During rainy days, most residential facilities release their liquid waste from their toilet facilities (septic tanks) into the public drains system (Monney *et al.*, 2013). It is common in the country to see polyethene bags, tin cans and their content floating on the surface of water bodies. Almost all water bodies in Tema, Accra and other

major towns are now being used as dumping pits and you would be turned down by unpleasant odour that would permeate into, and arrest your breath as you enter any major city in Ghana. People often defecate in broad-day-light into river or stream in the city and town centers of Ghana. Agricultural run-off from farming activities along streams introduces harmful chemicals such pesticides and weedicides into water bodies and also destroy natural vegetation cover (Sam-Okyere, 2015).

Industrial effluents and sewage spillages from burst pipes in city centres of Ghana enter water bodies directly as well as wetlands which finally flow directly into the sea. With the prevalent economic hardship in Ghana, most of the industrial effluents are discharged directly into streams and river bodies partly or without any form of treatment.

Industrialization is rapidly expanding in Ghana particularly in the Tema Metropolis which happens to be one of the areas with rapid industrial growth. Industry is growing in this area because the Ghana Government has zoned it for industrialization. However, there has been little regard for the effects of most industrial wastes to the environment and its adverse impact.

Today, the most affected part of the environment is the surface water resources. The routine monitoring of industrial effluent by Nerquaye-Tetteh and Abdalla (2013), of the Environmental Protection Agency, Ghana found that most industries in the country do not have wastewater treatment systems and even where present, they are either not properly designed or built.

With the increase in industrial activities, there is simultaneous increase or occurrence of pollution in the nearby environment through industrial effluents and gaseous emissions. High levels of toxic substances emanating from factories and other anthropogenic activities have been found in the Sakumono Lagoon into which the Onukpawahe drain which is an indication of industrial pollution (Agbemehia, 2013).

2.3. Nature and Characteristics of Industrial Effluents

It is common practice for industries to anticipate that their effluent could be discharged directly into the sewer systems. However, regulating bodies in Ghana must not allow any effluent released directly into the central sewer system without knowing the nature and constituents of these effluents, the capacity of the central sewer system to hold these effluents and the impact of the effluent on the various sections of the central treatment facility. The effluent quality guideline that has been prescribed by Environmental Protection Agency base on the level of concentration that must be discharged into natural water body or central sewer system is a way to preserve the central treatment system and the natural water bodies (Table 2.1A, appendix 8). Also, raw water quality guidelines have been developed by Water Resource Commission (WRC) for domestic and agricultural use (Table 2.1B, appendix 8). These tight effluent quality guidelines are to deal with the elimination of nutrients and contaminants. When effluent is to be put into another used, guidelines or standards normally include requirements for the removal of organics substances and heavy metals.

According to Walakira (2011), wastes from animals, humans and industrial effluents from industries contains organic substances for example protein and carbohydrates as the main pollution load. Microbes degrade these organic matters very rapidly when released into water bodies. New microbial cells are produced from these organic substances when the major part of it is converted into carbon (IV) oxide and the microorganisms finally die to serve as a source of food to other organisms known as decomposers.

In a water body, high levels of dissolved oxygen serve as lifeline for most aquatic organisms whereas reduction in dissolved oxygen levels due to the release of these organic substances into the water bodies. The decomposers proliferation is enhanced posing danger to other aquatic life. Activities of anaerobic organisms enhance organic matter degradation, which may not necessarily require oxygen, when there is high amount of oxygen demanded due to these organic

substances; high amount of the dissolved oxygen is lost from this water body or stream leading to unpleasant stench from volatile organic acids and gases.

2.3.1. Industrial Pollution

Industries which are the major source of water bodies' contamination and pollution are grouped into various sectors. The sectors are wood processing, food and beverages, brewery, textiles, energy, mining, pharmaceutical, paint and chemicals and pulp and paper. In the production processes of all these sectors water form an essential part as raw material, whereas less quantity remains as part of the manufactured product. The process water known as effluent or waste water become a source of pollutants or contaminants.

2.3.2 Effects of water pollution

When pollutants are introduced into water bodies from any possible source of pollution the water is eventually polluted with toxic substances which threaten human and aquatic life. The consequences could be very disastrous depending on the level and the type of these contaminants or pollutants. The effect and consequences of stream contamination or pollution differs depending on the type of substances discharged and which place was it discharged. According to Agbemehia (2013), the effect of water pollution originates from primary and secondary pollution. Streams that are located in city and town centers are contaminated and polluted which could be attributed to indiscriminate discharge of industrial effluent, domestic waste, and waste from health facilities, educational institutions and commercial areas. The consequences and effects of the pollution of water bodies is that it deprive microorganisms, fishes and other aquatic life the benefit that enable them to rely on this water bodies for survival. Examples of these consequences are reduction of light penetration ability through water due to farm lands runoffs which may contain dissolved particles. This phenomenon impairs the food production process by this aquatic plant that is photosynthesis will be reduced (Agbemehia, 2014). The

microorganisms have the capacity to bioaccumulate some of these toxic pollutants such as copper, cadmium and lead which may end up disrupting the normal food chain. They found their way to the food chain when these organisms are ingested by fishes which continually interfere with the food chain at higher tropics levels.

2.3.3 Effect on Aquatic and other forms of life

Aquatic animals whose survival depends on the good quality of water body with high level of dissolved oxygen concentrations are trashed due the introduction of pollutants into water bodies. Many other animals life including human beings may also be affected by high level of pollutions.

2.3.4. Damage to property

Acidic industrial waste discharge from industries could damage property through corrosive attack. Contaminated stream water used in plants for cooling purposes could also damage pipes, pumps, valves and other equipment in the plants, and registered as damages to properties as a result of stream pollution. According to eschooltoday (2015), the example of water pollution damage is the lost of over 8000 animals when US coastline was affected by oil spill.

2.3.5. Economic Loss

Various monetary consequences are usually resulted due to contamination of our water bodies by discharging effluent and toxic pollutants into them. When highly toxic pollutants are released into water bodies could lead to dissolved oxygen depletion which consequently results in the death of aquatic fishes depriving people who depend on these fishes of their economic livelihood. The consumers of these fishes from these fishermen are also weary of the source for fear of contamination (eschooltoday, 2015). Portable water which is obtained from polluted water body turn to be more expensive due to high cost of treatment of this water for drinking and domestic purposes and that means the nation or the company loses revenue. The Weija Dam for example

is constructed on the Densu River which has been polluted by anthropogenic activities along the river. Financially, it cost the Ghana Water Company Limited a lot of money in treating the water for consumption due to high nutrients load.

2.4 Water Quality

Ernest (2010) defined water quality as the physical, chemical, biological and aesthetic properties of stream or water body which establishes its suitability for the intended purpose and saving the health and integrity of water ecosystems. Water quality could be affected by nature's own patterns in many ways and forms. The quality of water such as streams, rivers, lagoons and lakes is affected by the seasonal patterns and geographical conditions, when pollutants have not been introduced. Poor quality of water may be due to natural processes but activities of human such as industrial development are the common cause. The main source of substances that can be harmful could be natural or anthropogenic, the impact from anthropogenic activities such as release of chemicals to the natural environment outweighs the natural sources (Bartram and Ballance, 1996). Thus, the state or the quality of surface water is affected by both natural conditions and human activities.

2.4.1 Physical and Chemical Characteristics

There are several essential physical indicators of industrial effluent which include turbidity, temperature, odour and colour (Mohammed, 2002). The most essential indicator of the quality of water is the amount of total solids which is made of suspended substance, colloidal substance, settleable matter and other substance in solution. The suspended solids, dissolved solids and settleable substances constitute the total solids. Surface water containing high suspended solids is not fit for bathing, industrial and other uses.

2.4.1.1 Temperature

The temperature of water is influenced by ambient temperature or air temperature, runoff from earth surface and sunlight or radiation from the sun. It is an essential parameter due to its influence on chemical reaction, aquatic survival and the purpose of usage of the water. The health and the life of the aquatic organisms is affected by temperature, it is therefore necessary to reflect deeply on the highest and the optimum temperatures at which the organisms survive. The factories that use stream or river as a source of cooling water are always wary of the temperature of intake water.

2.4.1.2 Conductivity

Conductivity is a function of total dissolved solids (TDS) known as ions concentration, which determines the quality of water (Tariq *et al.*, 2006). It normally indicates the concentration of dissolved ions in the stream. A high level of electrical conductivity is an indication of pollution of the stream. According to Mosley *et al.* (2005), conductivity estimates the total amount of salt for example, chloride, nitrate and so on present in the stream or water body, high levels of ions in the water indicate high electrical conductivity. To identify possible water quality problems promptly, electrical conductivity measurement is employed because the results are obtained instantaneously by immersing conductivity probes in the water.

Naturally, stream and rivers have some levels of dissolved particles as a result of rock weathering and dissolution of soil which may add a lot to electrical conductivity. Stream which contains elevated levels of conductivity are unwholesome for consumption. According to Akbar and Khwaja (2006) release of high levels electrical conductivity effluent would influence the life of organisms in the water and eventually the host stream would have a poor quality and cannot be used for beneficial purposes.

2.4.1.3 pH

The pH is used to determine the acidity or alkalinity of a solution. It is an important quality parameter of industrial effluent. The range of pH suitable for existence of most aquatic life is very small and critical. Biological means could not be used in treating most effluent with an adverse concentration of hydrogen ion and hence it is important to bring the pH to the optimum for proper treatment. The pH scale ranges between 0 and 14 with the neutral situation having a pH of 7 (Chapman, 1996). The pH of water varies during daytime and could rise to a high level of 10 when the water body has a lot of algae concentration in it where the carbon (IV) oxide is used by these aquatic plants in photosynthesis. According to Mosley *et al.* (2005), water with a pH > 8.5 could indicate that the water is hard. With an increasing acidity most trace metals become more water soluble and more harmful. The toxicity level of cyanides and sulphides increases with increasing acidity. The dynamics pH determines the content of toxic forms of ammonia to the non-hazardous form.

2.4.1.4 Turbidity

Turbidity is an optical determination of how clearer the water body is (Kemker, 2015). Turbidity occurs due to the presence of particles suspended or dissolved in water that scatter light making the water appear cloudy or murky. The suspended or dissolved particles involve sediment especially clay and silt, algae, soluble colored organic compounds, fine organic and inorganic matter, and plankton. Colour could influence the physical nature of the water body and this will indicate that the water is turbid which would look cloudy. There is practical correlation between suspended solids and turbidity from the activated sludge process while generally there is no known relationship between suspended solids and turbidity of effluent that has not been subjected to chemical or physical treatment (Mohammed, 2002).

Sediment settling out of the water column could lead to benthic smothering as an effect of turbidity on aquatic organisms (Smith and Davies-Colley, 2002).

An elevated turbidity levels harm fish and other aquatic life by reducing food supplies, degrading spawning beds, and affecting gill function. High turbidity enhances elevated numbers of foreign microbiota due to high total suspended solids in the water body, increasing microbial pollution.

2.4.1.5. Total Suspended Solids

The most common source of total suspended solids is soil erosion coming from the surrounding environment cause by anthropogenic activities (Fawaz *et al.*, 2013). Many industrial effluent such as food and beverage, cannery, sawmills, pharmaceutical and paper effluents normally contain considerable quantity of suspended solids. The treatment plants are used to screen these particles. The sludge is then dewatered by pumping on to drying beds. The solids are classified based on their volatility at $550 \pm 50^{\circ}\text{C}$ into categories (Mohammed, 2002). At this selected temperature, the organic part is oxidized and driven off as gas while the inorganic portion remains as ashes. The organic and the inorganic content are termed as volatile suspended solids and fixed suspended solids respectively. High TSS levels usually increase the levels of turbidity, BOD, COD and other parameters which impact negatively on human and the aquatic environment.

2.4.1.6. Total Dissolved Solids

Total dissolved solids (TDS) refers to the amount of dissolved inorganic salts, silt, organic substance and other particles (Hussain and Rao, 2013). The amount of TDS is usually relative to the extent of contamination of the water or stream body. A stream or water body with high TDS is a reflection of other water quality related problems and may have unacceptable levels of dissolved salts and impact negatively on aquatic microorganisms.

2.4.1.7 Colour

Type of industry influences the colour of the industrial effluent and varies accordingly. The measurement of colour and characteristics is essential in effluent quality monitoring. The coloured substance, most often exist in solution, certain ratio of these coloured substances could

be removed by the use of activated sludge and dribbling filters as secondary treatment units. For the removal of coloured matter sometimes require chemical oxidation devices (Mohammed, 2002). The presence of coloured organic substance such as humic substances, iron and manganese influence colour in industrial effluent or drinking-water. Drinking-water of good quality should be colourless.

2.4.1.8 Nitrate and Nitrite

Nitrate (NO_3) is important plant nutrient which exist naturally in the environment. It is part of the nitrogen cycle and present in all plants at varying concentrations. Nitrite (NO_2) concentration is most often present in the environment in small quantity except in a reducing environment, since nitrate is the most stable form of nitrite. Nitrite is normally produced in the reduction of nitrate by microbial activities. Due to runoff from farm lands treated with fertilizers, ingestion by phytoplankton and denitrification by bacteria concentration of nitrate in surface water usually changes very fast. The usual and essential source by which man get in touch with nitrate and nitrite is through consumption of food (vegetables and meat) which has been preserved with nitrate containing substances and vegetables.

2.4.1.9 Chemical Oxygen Demand (COD)

The chemical oxygen demand (COD) is refer to as the amount of oxygen required to decompose the organic substances in water body where these substances are decomposed by agent like potassium dichromate in the presence of sulphuric acid (Chapman, 1996). The chemical Oxygen Demand of industrial effluent is relatively greater than the Biochemical Oxygen Demand which is due to the fact that most of the chemical substance are easily degraded in this process than that of biological degradation process (Mohammed, 2002). The Chemical Oxygen Demand values can be determined in two to three hours and can therefore be very useful compared with the 5 days for the Biochemical Oxygen Demand. The levels of chemical oxygen demand usually found

in stream ranges between 20 mg/l in uncontaminated streams and higher of 200 mg/l in stream used as sinks for industrial effluent (Chapman, 1996). Manufacturing factory could obtain chemical Oxygen Demand values between 100 mg/l O₂ to 60,000 mg/l O₂ (Chapman, 1996).

The ratio of chemical oxygen demand to Biological Oxygen Demand is normally 1.5:2 for industrial wastewater containing more biodegradable substance (Mohammed, 2002). With wastewater ratios greater than 3, the assumption is that some oxidizable substance in the sample is non-biodegradable. Non-biodegradable substances are usually found in wastewater from chemicals and pulp and paper industries.

2.4.1.10 Biochemical Oxygen Demand (BOD₅)

Lokhande *et al.* (2011), defined Biochemical Oxygen Demand as the amount of oxygen consumed by microbes in the process of degrading organic substance in the stream water body over a period of five days under a specific temperature of 20°C. The most widely known source of Biochemical Oxygen Demand is the release of factory effluents, decay of plant and animals, crop wastes, runoff after precipitation and domestic sewage. Biochemical Oxygen Demand is usually used in estimating organic load in a stream or river. the maximum permissible BOD content before discharged into natural water body by EPA is 50mg/l (EPA , 2012).

2.4.1.11 Biological Characteristics

Most industries such as slaughter houses have certain pathogenic organisms and others like starch and yeast factories have molds and fungi (Mohammed, 2002). Certain indicator organisms are tested for in a biological test on effluent which determines whether pathogenic organisms are present. Effluents before its discharge to the environment, biological information are required to assess the extent of treatment needed. The effluent quality guidelines for the discharge of different industrial effluents into natural water bodies are shown in (Table 2.1, appendix 7). The amount of nitrogen is the most often measured parameter which exists in the form of urea,

organic, organic nitrogen compounds (amines, proteins, etc) and processed chemicals. The existences of such substances rely on the manufacturing process.

2.4.2 Heavy metals

Dankwah (2011) defined heavy metals as elements that have an atomic weight from 63 to 200. There are other proposed definitions (Duffus, 2002) which are based on other properties such as density, chemical properties or toxicity. Victoria (2009) reported that heavy metals occur naturally as part of the soil in the earth which is non-biodegradable.

The important constituents of most industrial effluents include trace metals, such as nickel (Ni), manganese (Mn), lead (Pb), chromium (Cr), cadmium (Cd), zinc (Zn), copper (Cu), iron (Fe), and mercury (Hg). The metals are toxic and their presence in effluent or drinking water source in high concentration will impact negatively on the beneficial uses of the water therefore, measurement and controlling of the concentration of these metals regularly is necessary (Mohammed, 2002).

Many of these metals are essential to the health of the organisms that live on this earth, including humans. These essential metals to human body include Co, Fe, Mn, Cu, Selenium, and Zn (Duffus, 2002). These heavy metals are required by living organisms in certain quantities. However extreme levels could be disastrous to many living organisms. There are no known important effects of lead and mercury on organisms but they turn to be very toxic metals and when bioaccumulate over a period in the bodies of these organisms could lead to complex health situation (Dankwah, 2011). Streams that passes through industrial areas which are dealing with manufacturing, slaughter houses smelting, welding, renovation and disposal of car batteries, petroleum and oils have been found to be polluted by toxic heavy metals (Pb, Cu, and Cd) (Ezeronye and Ubalua, 2005). These high concentrations poses the problem of disequilibria of the natural ecological balance of streams or rivers (Ezeronye and Ubalua, 2005).

Cadmium is bioavailable and toxic and impacts on plants metabolism and would persistently remain in microorganisms in the water once ingested it may also get into normal food chain (Walakira, 2011). Heart related disease and renal tubular diseases are the main protracted impact of cadmium intake even in low levels. The following symptoms; nausea, vomiting, and abdominal pain are influence by intake of extreme levels of cadmium. Most batteries including Ni- Cd batteries are usually made of about 70% cadmium and most of the remaining percent is use for pigments, stabilizers for plastics, and coatings and plating. Cd when ingested by the microorganisms" bioaccumulate in the body of these organisms for decades which may be removed through excretion at the end. The copper, lead, zinc and cadmium causes complex health problems to human consumers of fish which bioaccumulate these metals (Lokhande *et al.*, 2011).

Lead is a highly toxic metal found in natural deposits that are found in materials around us (Fakayode, 2005). Lead is among the recycled non- ferrous metals and its production has therefore grown steadily despite declining lead prices (Fakayode, 2005). Due to the properties of this metal it found much uses in the paint and other manufacturing industries. Acute effect of lead are; poor memory, hallucinations, delusions and irritability which manifested in acute intoxication. Lead affects children in their growth and bone stores of lead when it is ingested.

Lead metal is widely used in variety of products such as paints, car batteries and petroleum products or additives. Lead is no longer use in gasoline in Ghana since the lead was phase out in 2006. In countries where lead is still used in fuel continue to pose health risk due to accumulation of this metal in soil and plant leaves on frequently used roads and express ways. The animals especially cattle who graze on these leaves also carry the lead through the food chain.

2.5 Water and Effluent Quality Standards and Monitoring

The most common problems in third world countries like Ghana is availability of data on water quality and information for decision making (Bernard, 2010). The implementations of effluent monitoring programmes are important in the developing of effluent and water quality regulations and enhance building capacity in monitoring and evaluation. Various kinds of effluent and water quality guidelines are essential to effluent monitoring and management programmes.

2.6 Water Quality Standard and Monitoring

Water quality is referred to as all the properties (physical, chemical and biological) of water which reveals whether the water is healthy for the intended use or the environmental conditions of stream or river. The properties are usually influence by matters which may be floating or mixed with water (Mohammed, 2002).

The Clean Water Act described water quality as the standard purity (unmixed with extraneous materials) of the stream which is essential for the preservation of aquatic life and number of wildlife in the aquatic environment and also use for refreshment in and on the water body (Wenner and Geist, 2001). The Environmental Protection Agency and Water Resource Commission developed water quality guidelines for physico-chemical variables that are to meet the intended used of the water (EPA, 2012; WRC, 2003). The effluent quality guidelines have shown the acceptable levels or concentration before discharged into natural water body for all the physico-chemical parameters. Achievable objectives must be maintained to enhance the intended use since the water quality guideline values explain but not to measure conditions. Water quality monitoring programmes provides information on pollution trends. The water quality usually will provide information for assessment of state of the water body in relation to anthropogenic activities and natural conditions (Chapman and Kimstach, 2002). Few water

quality variables that provide general conditions are measured, due to complexity of assessing the overall condition or state of the water body.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

The Onukpawahe stream is among the four major streams that drains into the Sakumonu Lagoon which is a coastal lagoon situated 3 km west of Tema. The stream lies between longitude 5° 39'24" to 5° 39'35" N and latitude 0°5' 22" to 0°3'20" W. The Sakumono Lagoon which is internationally recognized wetland. The catchment area is about 350 km². The major streams that drain the basin is; Onukpawahe, Mamahoma, Dzorwulu and Gbagbla-Akornu streams. The Onukpawahe stream is a major source for agriculture (i.e. fruit and vegetables) activities located in upstream and downstream areas and is about 12.8 km long. The study was carried out in Onukpawahe stream that transverse the Tema Motorway industrial and in effluent channel from six (6) industries (Table 3.1). Figure 3.1 is showing the study area and sampling locations.

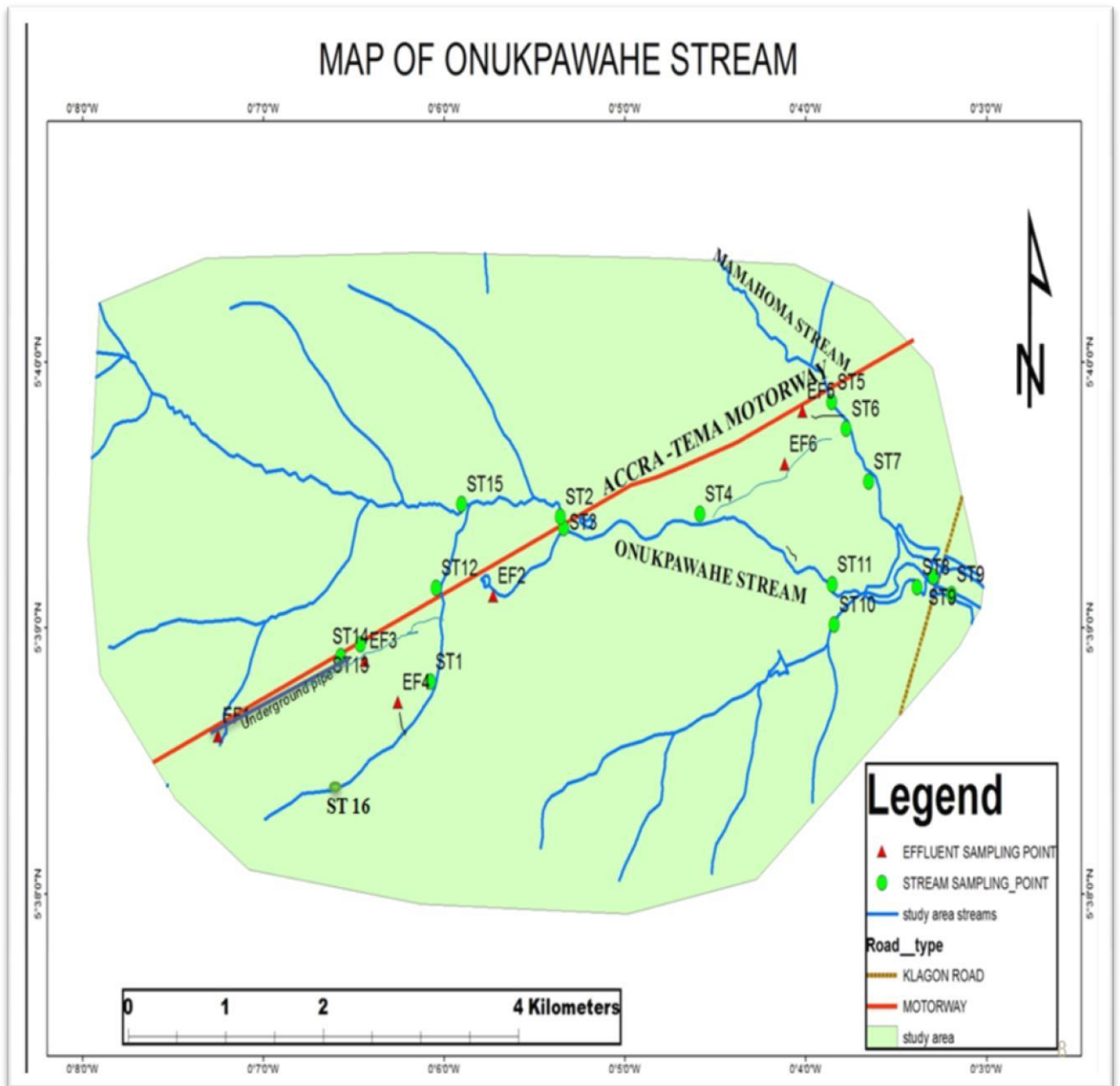


Figure 3.1: Map showing the study area and sampling locations

Table 3.1: Industries assessed, their respective production activities and effluent management

INDUSTRY	ACTIVITY	EFFLUENT MANAGEMENT	CAPACITY (WWTP)

The Coca Cola Bottling Company of Ghana Limited (TCCBCGL)	Beverage industry i.e. producers of soft drinks (i.e. Fanta, Coke etc) and water	Biological Wastewater Treatment Plant	2000m ³ per day
Kasapreko Company Limited(KCL)	Manufacturer of alcoholic beverages	Discharge into drain which eventually flow into stream	-
Nutrifood Ghana Ltd	Manufacture of biscuits	Discharge into drain which eventually flow into stream	-
Healthilife beverages Limited	Manufacturer of Fruit juice	Wastewater Treatment Plant (WWTP)	65000m ³ per day
Accra Abattoir Company Ltd	Slaughter house	Discharge into drain which eventually flow into stream	-
Printex Ghana Ltd	Textile manufacturers	Wastewater Treatment Plant (WWTP)	5000m ³ per day

3.2 Study design

The study involved sampling of effluents from six (6) industries i.e. The Coca Cola Bottling Company Limited (TCCBCGL), Kasapreko Company Limited (KCL), Nutrifood Ghana Ltd, Healthilife Beverages, Accra Abattoir and Printex Ghana Ltd and at fifteen (15) selected points along the Onukpawahe streams that drain Tema Motorway industrial area (Fig. 3.1). The above industries mainly discharge their effluents into the Onukpawahe stream.

3.3 Sampling

The sampling took place for five months (October 2015 - February 2016). The period between October - November, 2015 were considered the wet season, while the period between December, 2015 – February, 2016 were considered the dry season. Samples were collected from effluent channels leading to the stream and from fifteen (15) sampling sites ST1, ST2, ST3, ST4, ST5, ST6, ST7, ST8, ST9, ST10, ST11, ST12, ST13, ST15 and ST16 along the stream (Table 3.2). The GPS Coordinates were recorded for each sampling site. The sampling points were designed in relation to industries as depicted by Fig. 3.1. All samples for laboratory analysis were placed into thoroughly cleaned (with dilute HNO₃ and rinsed with distilled water before use) 1litre plastic bottles and glass bottles. Each of these bottles was rinsed with appropriate amount of water or effluent sample before collection of the sample. The samples were placed in cooler boxes which were protected from sunlight before taken to laboratory for analysis.

Table 3.2: Coordinates and sampling site

No.	Sample ID	Location	Coordinates	
1	EF1	Printex Ghana Ltd	5.55029N	0.06861W
2	EF2	Healthilife beverages Ltd	5.65202N	0.09548W
3	EF3	The Coca Cola Bottling Company of Ghana Limited (TCCBCGL)	5.64794N	0.10734W
4	EF4	Kasapreko Company Limited (KCL)	5.64535N	0.10426W
5	EF5	Nutrifood Ghana Ltd	5.66360N	0.06697W
6	EF6	Accra Abattoir Company Ltd	5.66029N	0.06861W
7	ST1	Kasapreko entry point to stream	5.64661N	0.10129W
8	ST2	Upstream across Motorway Bridge	5.65696N	0.0893W
9	ST3	Stream Healthilife Entry point	5.65627N	0.08897W
10	ST4	Mid-stream Community 18 Bridge 1	5.65713N	0.07644W
11	ST5	Upstream of Mamahoma before joining Onukpawahe stream	5.66419N	0.06426W
12	ST6	Downstream after Abattoir and Nutrifood	5.66251N	0.06293W
13	ST7	Downstream of Mamahoma after Joining Onukpawahe stream	5.65919N	0.06087W
14	ST8	Stream sampling point before the Klagon Bridge	5.65255N	0.05642W

15	ST9	Downstream sampling point after the Klagon Bridge	5.65208N	0.05324W
16	ST10	Stream from Community 18 bridge 1	5.65022N	0.06406W
17	ST11	Stream from Community 20 Bridge 2	5.65274N	0.06423W
18	ST12	Downstream of tributary joining Onukpawahe stream	5.65248N	0.10075W
19	ST13	Printex and Coca Cola entry point to stream	5.64896N	0.10771
20	ST14	Stream before Printex and Coca Cola entry point to stream	5.64821N	0.10955W
21	ST15	Stream after Kasapreko, Printex and Coca cola entry point	5.65777N	0.09839W
22	ST16	Upstream before Kasapreko Discharge into the stream	5.64661N	0.10129W

3.3.1 Description of sampling points

- A. Upstream (US) - is the upper part of the stream before the discharge enters it. It has a number of vegetable farms which depends on the stream as a source of irrigation.
- B. Mid-Stream (MS) - is the middle part of the Onukpawahe stream is settlement and has a number of vegetable farms which depends on the stream as a source of irrigation. There are other activities such as washing bays and mechanic shops.
- C. Downstream (DS) - is the down part of the stream and receives effluents from industries, runoff from agricultural farms, storm water and domestic effluents through the streams.
- D. The Coca Cola Bottling Company of Ghana Limited (TCCBCGL) - is soft drinks and other non-alcoholic beverages manufacturing company. The factory generates effluent from its processes. The effluent from the factory includes spilled products, caustic soda and liquid soap for washing and cleaning, oil and grease from machine parts. These effluents are sent to an effluent treatment facility installed in the factory for treatment before discharging into the stream. The samples were collected for analysis from the outlets of the factory before the effluents flow into the Onukpawahe stream.

- E. Kasapreko Company Limited (KCL) - is an alcoholic beverages manufacturing company and generates wastewater in the process. The company has no effluent treatment facility. the effluent are therefore not treated before discharged into the Onukpawahe stream. Samples were taken immediately from the outlets of the company before it flows into the tributary of the Onukpawahe stream which finally joins the Onukpawahe stream at some point.
- F. Printex Limited (PL) - Printex is a textile and garment manufacturing company. The company manufactures different designs and brands. The main wastes generated from the factory's processes are dye-laden wastewater. Printex has an effluent treatment plant where effluent is treated before discharge into stream. Samples were taken from the outlets of the company after treatment before it flows into the Onukpawahe stream.
- G. Healthilife Beverages Limited (HBL): The Healthilife Beverages Limited is a limited liability company which is a subsidiary of the KINA GROUP. The company is located at the Motorway Industrial Area, near the Coca Cola Bottling Company Limited. The company is fruit juice and evaporated milk producing company. It has an effluent treatment plant with a discharge capacity of 65000 m³ per day. Samples were taken from the outlets of the company after treatment before it flows into the Onukpawahe stream.
- H. Nutrifood Ghana Limited: Nutrifood Ghana Limited is a modern biscuits manufacturing plant with an installed monthly operation capacity of 774 MT. The company produces various types and brands of biscuits for the Ghanaian market. The facility discharges its effluent directly into the Onukpawahe stream without any form of treatment. Samples were taken from the outlets of the company before it flows into the Onukpawahe.

3.4 Analyses of industrial effluent and water samples

The industrial effluent and water samples were analyzed in the following laboratories;

Environmental Quality Laboratory- EPA and Envaserve Environmental Consult Laboratory Accra. Standard Methods for Examination of Water and Wastewater (APHA ,1992), was followed for the analysis of the samples.

The analysis of the physical parameters of the effluent and water sample was carried out insitu using multi-parameter water quality meter (**Horriba U-52G**). The following parameters were measured in situ; pH, Temperature, Turbidity, DO, Conductivity and TDS

3.4.1 pH

The pH was measured in the effluent collection point and in the stream respectively by the use of a multi-parameter water quality meter (Horriba U-52G).

3.4.2 Conductivity

The electrical conductivity was measured in-situ both in the effluent channel and in the stream using a multi-parameter water quality meter (Horriba U-52G). The conductivity meter was put on and probes immersed into the stream after stabilization. The concentration of the conductivity was displayed on a screen which was recorded in ($\mu\text{S}/\text{cm}$)

3.4.3 Turbidity

The multi-parameter water quality meter (Horriba U-52G) was used in situ to determine the level of Turbidity in (NTU).

3.4.4 Colour

The Wagtech Potalab Photometer 7100 was used to determine the colour of the samples.

- The samples were filtered through a filter paper.
- A test tube was filled with the filtered samples to the 10 ml mark.
- Another test tube was filled deionised water to the 10 ml mark and use as BLANK

tube.

- The colour was read directly in True Colour Units (TCU) on Wagtech photometer using deionised water as the blank (Wagtech, 2015; YSI, 2014).

3.4.5 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) referred to as the amount of oxygen consumed to degrade organic substances in the stream.

- 2ml of the water sample was mix with already known quantity of standard solution of potassium dichromate ($K_2Cr_2O_7$) in the presence of sulphuric acid in test tube.
- The content was heated at the temperature of $150^\circ C$ for two hour period.
- It was allowed to cool to room temperature and the reading was taken on Wagtech Potalab Photometer 7100 photometer in $mg/l O_2$ (Wagtech ,2015; YSI, 2014).

3.4.6 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD_5) was determined by the Velp Scientific System. The Velp system uses BOD sensor which is enhanced with microelectronics. The sensor displays the data for every 24 hours for five day period. The sensor uses lithium batteries.

- The pH of the samples was brought to between 6.5 to 7.5 to remove toxic metals and proper bacteriological activity. 100 ml of the sample was placed in 500ml BOD bottle.
- Magnetic stirrer was placed into the bottle.
- Potassium hydroxide (KOH) scales, commercial grade was placed in the alkali cup to absorb carbon dioxide produced during incubation.

- The BOD sensor was screwed directly on the bottle and incubates at 20°C for five days. The sensor record BOD every 24hrs for the five day period.
- The BOD recorded by the sensor was read on a displayed screen..
- Sample with high BOD were diluted and incubated same. BOD was calculated after reading the value as follows: $BOD (mg/l) = (BODa - BODd) \times DF$. Where BODa = BOD of diluted sample, BODd = BOD of distilled water used for dilution and DF = Dilution factor.

3.5. Nutrients

Analysis of nitrate, phosphate, sulphate and ammonia were carried out using reagents and Wagtech Potalab photometer 7100 (Wagtech ,2015; YSI, 2014). The analysis of these nutrients were carried out within 24 hours after sampling to avoid concentration changes

3.5.1 Phosphate – phosphorus

Wagtech phosphate reagent was used to determine the concentration of phosphate.

- The reagents were provided in the form of two tablets for maximum convenience.
- Test tube was filled to 10 ml mark with the sample.
- Phosphate no.1 and 2 tablets were added and crushed, mixed to dissolve and allowed to stand for ten (10) minutes for colour development.
- The Phosphate concentration was determined by direct reading on WAGTECH Photometer Model 7100 in mg/l (Wagtech, 2015; YSI, 2014).

3.5.2 Total Phosphorus

The Wagtech phosphorus test was carried in two stage procedure.

- The samples were digested with acid persulphate to break down polyphosphates and organic phosphorus compounds and convert them to orthophosphate.

- The resulting orthophosphate, together with that originally present in the sample, was then determined by reacting with ammonium molybdate and ascorbic acid to form the intensely coloured 'molybdenum blue' complex.
- Catalyst was incorporated to ensure complete and rapid colour development, and an inhibitor was used to prevent interference from silica.
- The total phosphorus concentration was determined using the Wagtech photometer model 7100 (Wagtech, 2015; YSI, 2014).

3.5.3 Nitrates

The Wagtech nitrates was use to estimate the concentration of nitrate. The reagents were provided in single Nitricol tablet and Nitratest powder.

- Nitratest Tube was filled with sample to the 20 ml mark. One level spoonful of Nitratest Powder and one Nitratest tablet was added and shaken well for one minute.
- The Nitratest tube was allowed to stand for about one minute and then gently inverted for four times to aid flocculation.
- The tube was allowed to stand for two minutes to ensure complete settlement.
- The clear solution was carefully decanted into a round test tube, filling it to the 10 ml mark.
- One nitricol tablet was added to the sample and vigorously shaken until it dissolves □ It was allowed to stand for ten minutes for full colour development.
- The concentration was determined by direct reading on WAGTECH Photometer Model 7100 at wave length of 570 nm (Wagtech, 2015; YSI, 2014).

3.5.4 Ammonia-nitrogen (NH₃ -N)

Ammonium-nitrogen was determined by Wagtech Ammonia test which is based on an indophenols method. A green-blue indophenols complex was obtained from the reaction

between the ammonia and the alkaline salicylate in the presence of chlorine. Catalyst was incorporated to ensure complete and rapid colour formation.

- The reagents were provided in the form of two tablets.
- Test tube was filled to the 10 ml mark with the sample.
- Ammonia No.1 and two tablets were added and crushed to mix and dissolved
- It was then allowed to stand for 10 minutes for colour development
- The ammonia concentration was determined by reading on Wagtech photometer Model 7100 at wave length of 640nm.

3.6 Microbiological Analyses

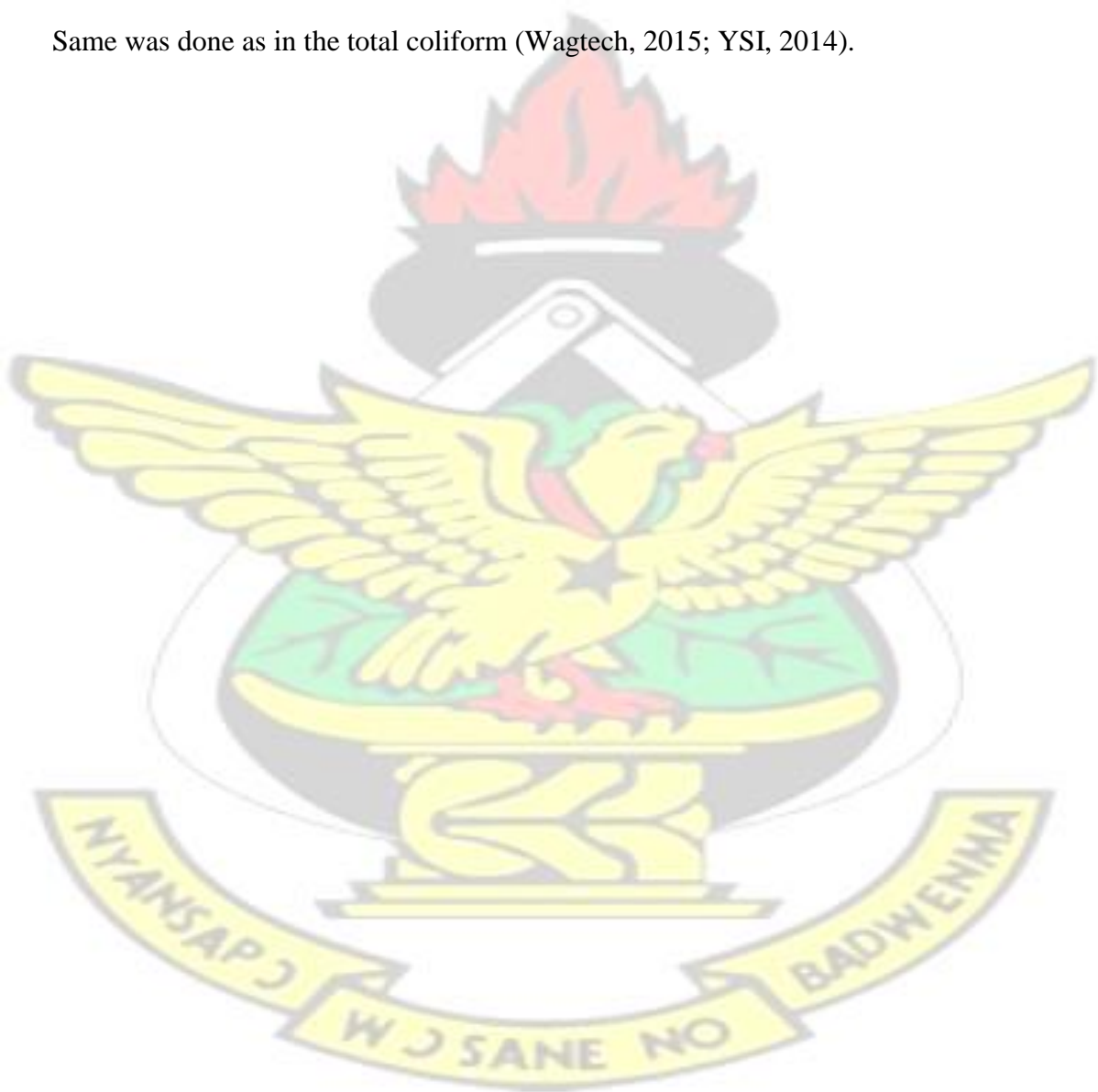
The Wagtech membrane filtration method was used in the detection of Coliforms. The water and effluent samples were filtered through the membrane that is capable of retaining the bacteria and incubated (Wagtech, 2015; YSI, 2014).

3.6.1 Total coliform determination

- The water and effluent samples were filtered through the membrane that is capable of retaining the bacteria.
- The membrane was incubated on membrane lauryl sulphate media measuring device (MMD) at a selected temperature of 37°C on the petri-dish which was loaded in rack and placed inside the incubator.
- It was incubated for minimum incubation period of 14 hours and 4hours resuscitation.
- The lid was removed and all yellow colonies were counted with a coliform counter.
(Wagtech, 2015; YSI, 2014).

3.6.2 Faecal coliform determination

- The water and effluent samples were filtered through membrane that is capable of retaining the bacteria.
- The membrane was incubated on a membrane lauryl sulphate media measuring device (MMD) at a selected temperature of 44°C and petri-dish which was loaded was loaded in rack and placed inside the incubator.
- It was incubated for a minimum incubation period of 14 hours following 4 hours resuscitation. Same was done as in the total coliform (Wagtech, 2015; YSI, 2014).



3.7. Heavy Metals

The content of all the heavy metal were determined by (SCHIMADZU AAS model AA7000) Atomic Absorption Spectrophotometer. Method 3005A (appendix 1) (Acid Digestion of Waters for total recoverable or dissolved metals for analysis by FLAA Spectroscopy) was used for the digestion of the samples. The most commonly used method due to the reproducibility of results.

3.8 CCME Water Quality Index

The Water Quality Index (WQI) was designed by Canadian Council of Minister of the Environment (CCME) (CCME, 2001). The WQI is simple mathematical expression of bringing all indicators into single value to determine how poor or excellent a water body is for beneficial uses. The WQI could be used in monitoring and assessing quality trends in the quality of stream or any other water body overtime (CCME, 2001).

The WQI depends on three measures of deviation from water quality guidelines. The three components are

- Scope (F1)
- Frequency (F2)
- Amplitude (F3)

3.8.1 Calculation of the index (CCME, 2001).

The estimation of F1, F2 and F3 is shown in the equation below.

- F₁ (Scope) is the percentage of fail parameters relative to the number of indicators analysed during period of monitoring.

$$F_1 = \left(\frac{\text{Number offailed variables}}{\text{Total Numberofvariables}} \right) \times 100 \quad (1)$$

- ii) F_2 (Frequency)- this indicates the percentage of each tests that do not meet guideline values (objectives).

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total Number of tests}} \right) \times 100 \quad (2)$$

- iii) F_3 (Amplitude) –this refers to quantity of fail test results which do not comply with guideline values. F_3 is usually obtained in three steps.

- a) “*excursion*” refers to the frequency by which each indicator value exceeds or (fall below, when the guideline value is a minimum) is estimated as follows.

□ When the test must not be greater than the guideline value (objective):

$$\text{excursion}_i = \left(\frac{\text{Failed Test Value}_i}{\text{Objective}_j} \right) - 1 \quad (3a)$$

When the test value must not fall below the guideline value:

$$\text{excursion}_i = \left(\frac{\text{Failed Test Value}_i}{\text{Objective}_i} \right) - 1 \quad (3b)$$

The excursions of the individual tests from their objectives are then sum up and divide by the number of tests (both failed and not fail to objective), and this give total amount by which each tests fail with respect to guideline value. The Variable is usually called Normalized sum excursion or *nse*);

$$nse = \frac{\sum_{i=1}^n \text{excursion}_i}{\text{no. of tests}} \quad (4)$$

- b) F_3 is the estimated as a scale of the *nse* to produce a range between 0 and 100.

$$F_3 = \left(\frac{nse}{0.01nse = 0.01} \right) \quad (5)$$

- iv) The CCME Water Quality Index (CCME WQI):

$$CCMEWQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \quad (6)$$

The 1.732 was as the normalized resultant values between 0 and 100 with 100 as excellent and 0 as poor as shown in the equation (6a) below.

$$1.732 = \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{100} \quad (6a)$$

The above formulae have been incorporated in excel **WQI Calculator**(CCME 2001)

The Standard form of the formula:

$$WQI = \sum W_x Q_x \quad (7)$$

Where

W_x represent the weight factors of the water quality indicators

Q_x represent the q value of the water quality indicator (parameters)

X represents the indicators

It's the standard formula to calculate WQI and gives best results (Srivastava and Kumar, 2013)

3.8.2 Existing Ranking System

The Water Quality index scale (Table 4.2, appendix 4) (CCME, 2001).

3.11 Data Analysis

The results obtained from the laboratory analysis and insitu measurement were entered into

Statistical Package for Social Science (SPSS) and Microsoft excel for the analysis. The CCME Water Quality Index was used to determine the overall quality of the Onukpawahe stream.



Plate 1: In situ measurement of physical parameters and Laboratory analysis CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

This section present results of physico-chemical, heavy metal and microbiological parameters of the stream water samples from selected points along the Onukpawahe stream and effluents samples from Six (6) selected industries; Coca Cola Company Limited, Kasapreko Company Limited, Healthlife Beverages Limited, Printex Ghana Limited, Nutrifood Company Limited and Accra Abattoir Company Limited. The stream water samples results were compared with the Water Resources Commission(WRC) raw water quality guidelines (WRC, 2003), while the effluent results were compared with the Environmental Protection Agency's effluent quality guidelines (EPA, 2012).

4.2 Physical and chemical parameters

The following physico-chemical parameters of the Onukpawahe Stream are presented in this section: temperature, total suspended solids (TSS), pH, turbidity, total dissolved solids (TDS),

and conductivity (EC) and chemical parameters: dissolved oxygen, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and nutrients such as sulphate, nitrate, phosphate and ammonia and heavy metals such as copper (Cu), Cadmium (Cd), zinc (Zn), Chromium (Cr), Lead (Pb) and Iron (Fe). The summary statistics of (mean \pm SD) values for the parameters measured in dry and wet season are presented in Appendix 2 (Table 4.1A, 4.1B, 4.1C and 4.1D).

4.3 Concentrations of water quality parameters in the Onukpawahe Stream

4.3.1 Temperature

Temperature values ranged from 28.8–34.3°C in the rainy season and 27.7–33.2°C in the dry season (Figure 4.1). Stations ST13 and ST12 located in the downstream for both dry and wet seasons recorded the highest value of 33.2°C and 34.3°C respectively. The results were within the WRC raw water quality guideline “no effect” range of $< 2^{\circ}\text{C}$ above ambient (WRC, 2003). Throughout the entire period of the study the temperature was found to increase progressively from upstream at ST14 to the downstream. Statistically significant differences were found between the sites (ANOVA, $P < 0.05$). The increase in the levels of temperature could be attributed to the discharge of industrial effluent from Textile and bottle washing plants (alcoholic and non-alcoholic beverages) which are usually associated with high temperatures (Kanu *et al.*, 2011). However, several factors such as the weather conditions, time of sampling and location also impact on the increase or decrease of temperature by which its role effect on the percentage of dissolved oxygen, biological activities, and other parameters (Fawaz *et al.*, 2013).

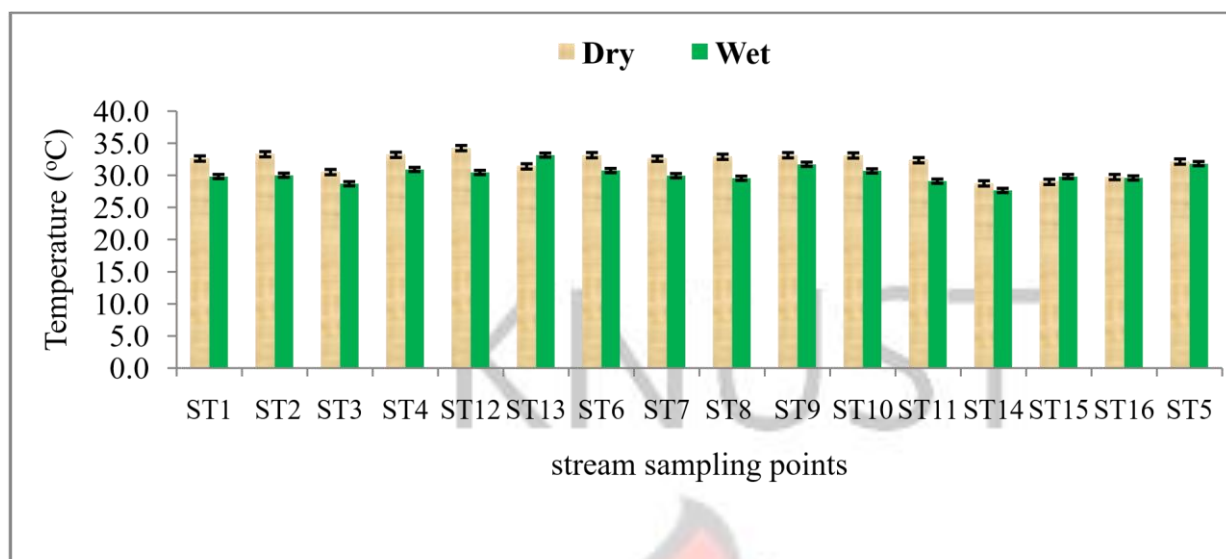


Figure 4.1: Temperature of the Stream

4.3.2 pH

The pH of the Onukpawahe stream ranges from 5.36 -10.05 in the wet season and 6.63 – 8.36 in the dry season (Table 4.1C and D, appendix 2). The highest pH values of 10.05 was obtained at station ST1 in the Wet season, whereas the lower mean values of 5.36 was obtained at station ST3 in the wet period (Figure 4.2). The low pH values were recorded at mid- stream stations ST2 and ST3 where most of the beverage industries including brewery industries are discharging their effluent into the stream (Figure 4.2). Effluent from an alcoholic beverage facility are release from raw material such as grains and yeast with peculiar stench of rancid malt and partially acidulous (Kanu *et al.*, 2011). The high pH at site ST1 (10.05) could be attributed to photosynthetic activities of algae that consume carbon (IV) oxide dissolved in the stream (Figure 4.2). However, the differences between the pH concentration were observed to be statistically insignificant (ANOVA, $p = 0.29$, $P > 0.05$). The pH values recorded in the stream were all within the WRC raw water quality guideline “no effect” range of 6.0–9.0 (WRC, 2003) except the pH values observed at sites ST1, ST2 and ST13 (Figure 4.2). These results shows that the toxic effects associated with dissolved metals are likely to occur at the pH less than 6

and the probability of toxic effects due to deprotonated species also increases sharply at pH above 9. An adverse health effect is expected under such pH level in the stream.

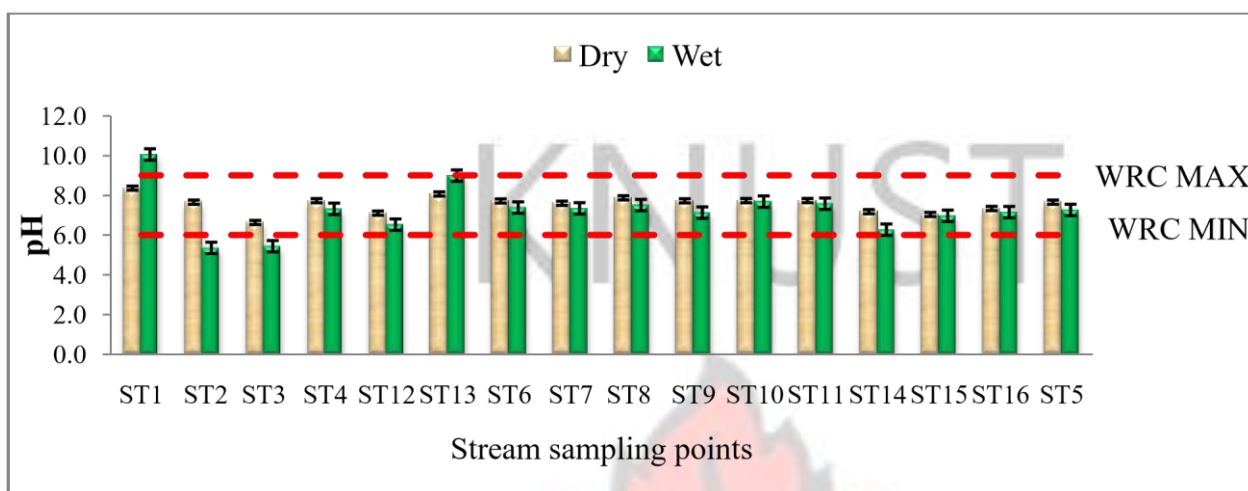


Figure 4.2: pH values measured in the stream (wet and dry period)

4.3.3 Dissolved Oxygen

DO is important in the determination of the quality of stream water and also assist in the understanding of the natural self-purification ability of water body as well as the impacts of urbanization and industrialization on water body (Hasan and Miah, 2014). The dissolved Oxygen (DO) levels in the stream water samples analysed were between 5.60 to 8.50mg/l in the wet period and from 4.70 to 7.90 mg/l in the dry period (Table 4.1C and D, appendix 2). The lowest DO was recorded at site ST6, whereas the maximum value was observed at site ST3 in the wet period (Figure 4.3). The results were within the WRC raw water guideline “no effect” range of 0-5mg/l (WRC, 2003) except site ST2 and ST6 (Figure 4.3). However, differences between sampling site was statistically insignificant (ANOVA, $P=0.522$, $P>0.05$). The low levels of DO concentration observed in the wet and the dry seasons at site ST6 which is some few meters from the discharge point of the Abattoir, could be attributed to the high levels of nutrients, organic substance and total solids in the effluent from the Abattoir which required high levels of oxygen to undergo degradation and hence reduce the amount of oxygen needed for respiration and eventually leads to the death of aquatic organisms.

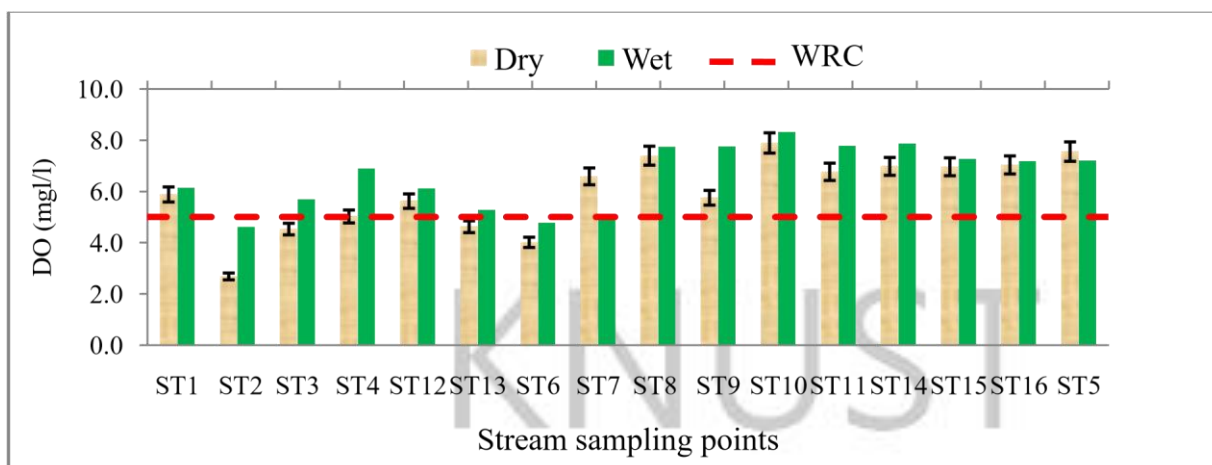


Figure 4.3: Levels of DO measured in the stream

4.3.4 Total Dissolved Solids (TDS)

The TDS recorded ranged between 173 mg/l and 2,503 mg/l in the wet period, whereas in the dry period it ranges from 71 mg/l to 1,785 mg/l (Table 4.1C and D, appendix 2). The highest value 2,503 mg/l in the wet season was recorded at the site ST6, while the lowest value of 173 mg/l was observed at site ST14 which is an upstream station (Figure 4.4). Similarly the highest TDS concentration of 1,785 mg/l was obtained at site ST5 in the dry season and the lowest value of 71 mg/l was recorded at site ST 14 (Figure 4.4). The TDS concentration recorded were above the Water Resource Commission (WRC) raw water quality guideline “no effect” range of 0-450 mg/l (WRC, 2003) except the upstream sites ST14, ST15 and ST16. During the dry period the level of TDS were much lower than the rainy season (Figure 4.4). The high concentration of TDS observed during the wet period could be attributed to runoff from farm lands that brought into the stream chemical materials such as phosphate, chloride and nitrates due to fertilizer and organic matter. It was realised that the total dissolved solids concentration in the upstream station were lower as compared to the downstream. This could be attributed to the release of industrial wastewater into the water body by the industries along the stream and a lot of anthropogenic activities occurring at the midstream than the upstream (Figure 4.4). The ANOVA ($P = 0.005$, $P < 0.05$) indicates that the difference in the concentration of TDS between

the sites is statistically significant. In the study, high values were also observed immediately after the point of discharge which strongly implicates industrial sources located within these areas. Adeogun (2012) and Chapman (1996) found that high TDS could be a direct measure of anthropogenic impact. TDS and Conductivity are influenced by the presence of inorganic substances such as phosphate, chloride and nitrate ions (Fakayode, 2005) and high levels of these ions in water body could lead to nutrient enrichment and high salinity which could affect aquatic life.

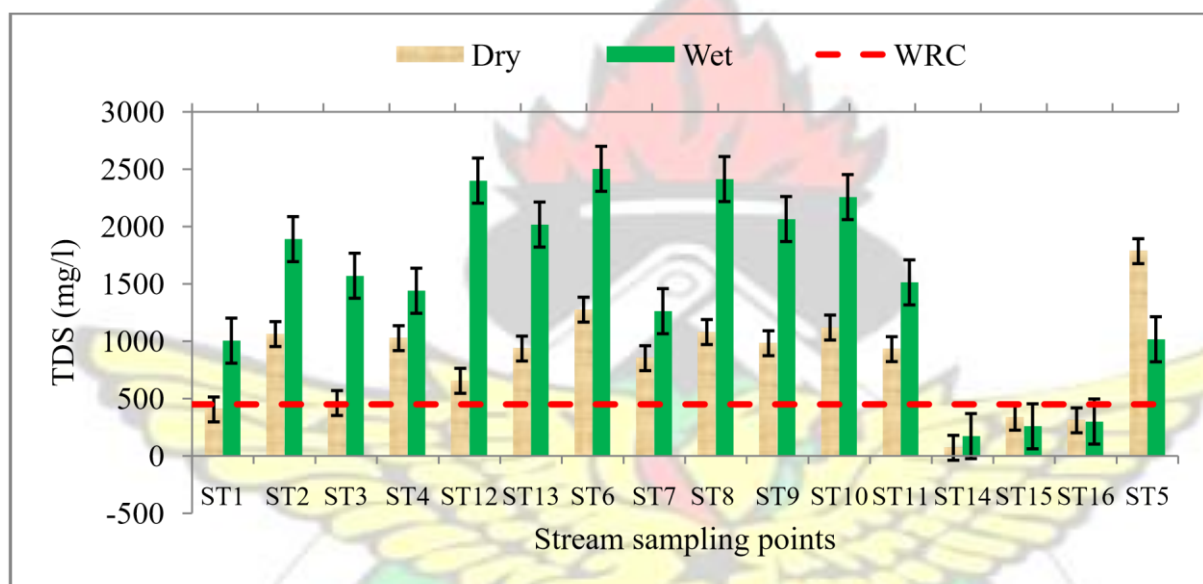


Figure 4.4: TDS measured in the stream

4.3.5 Electrical Conductivity (EC)

The conductivity ranges between 398 $\mu\text{S}/\text{cm}$ and 5,006 $\mu\text{S}/\text{cm}$ in the wet period and the minimum was observed at site ST14 (Table 4.1C and D, appendix 2), while the highest was at site ST6 (Figure 4.5). Similarly, conductivity varied in the dry season from 113 $\mu\text{S}/\text{cm}$ to 2,737 $\mu\text{S}/\text{cm}$ (Table 4.1 C and D, appendix 2) and the lowest value was obtained at site ST14, while the highest was at site ST5 (Figure 4.5). The conductivity levels observed in the stream water samples were above the Water Resource Commission (WRC) raw water quality guideline values “no effect” range of 0-700 $\mu\text{S}/\text{cm}$ (WRC, 2003) except upstream sites ST14, ST15 and

ST16. However, the ANOVA ($P = 0.001$, $P < 0.05$) indicates that the differences in conductivity levels between the sites is statistically significant. These levels of conductivity could be an indication of the presence of high quantities of inorganic ions such as phosphate, nitrates and chloride (Fakayode, 2005). According to Monney *et al.* (2013), in similar study stated that conductivity is influenced by existence of sodium, calcium and aluminium cations or substances such chloride, phosphate and nitrates in the stream. The high conductivity values observed in wet season could be attributed to possible run-off from farm lands along the banks of the stream. This is in contrast to findings by Monney *et al.* (2013), at the Korle Lagoon which shows high TDS values in dry period than the wet period. The highest conductivity values recorded at site ST6 (Figure 4.5) which is the immediate downstream site of the Abattoir could be attributed to the discharge of effluent with nitrogeneous substances in the form of partly digested food from the gut of slaughtered animals into the stream (Adeogun *et al.*, 2011).

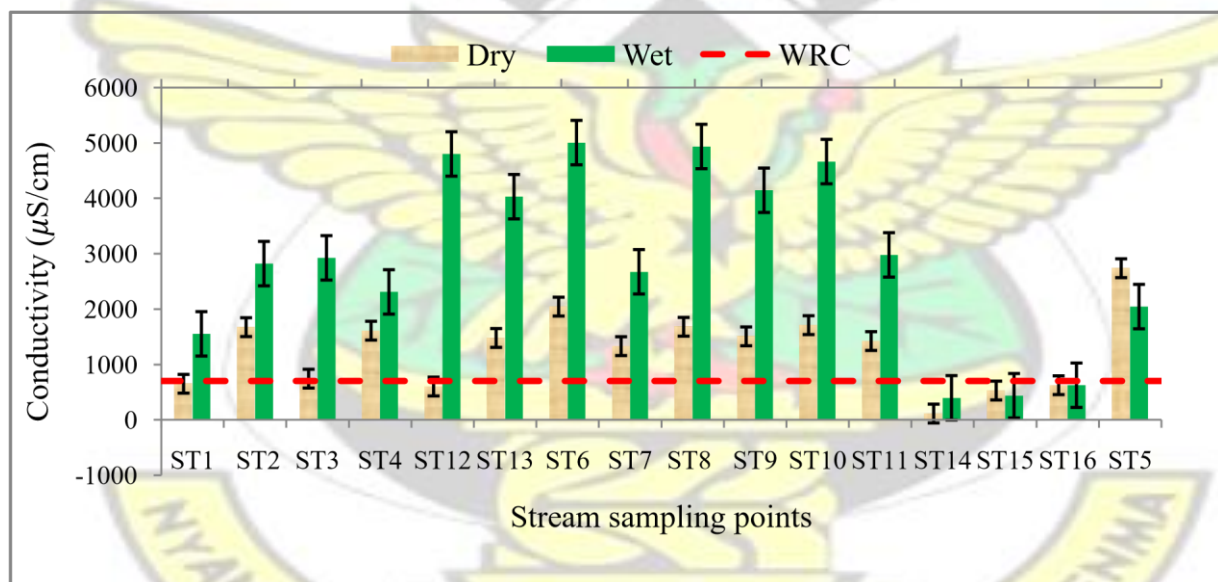


Figure 4.5: Electrical conductivity in the Onukpawahe stream

4.3.6 Turbidity

Industrial effluents with high turbidity values contribute extremely to high levels of solids into the water bodies. The turbidity levels observed in the wet season were between 11 NTU and 340 NTU, whereas it ranges from 9 NTU to 203 NTU in the dry season (Figure 4.6). The highest

turbidity was recorded at downstream site ST7 and the lowest was recorded at site ST10 which is located within residential areas (Figure 4.6). The turbidity values observed during the study were far higher than the WRC raw water quality guideline values the “no effect” range of 0–5 NTU (WRC, 2003). This implies that in the wet season, the stream carried an associated risk of disease transmission due to infectious disease agents and chemicals absorbed. However, the ANOVA ($P < 0.05$) indicates that there was a significant difference between the turbidity levels among sites. The high turbidity recorded at site ST7 could be attributed to the release of effluent with high suspended substance from the industries especially the Abattoir into Onukpawahe stream (Adeogun, 2012). The increase in turbidity could also be attributed to the discharge of textile effluent (organic substances), run-off from vegetables farms, roads and heavy precipitation into the stream. Pollutants such as dissolved metals which are associated with textiles industries and suspended substances serving as a source of attachment for microorganisms through which it enters water bodies. An increase in turbidity is an indication of erosion of stream banks which reduces habitat for fish and other aquatic organisms. According to Kemker (2015), excessive suspended sediment can impair water quality for aquatic and human life, impede navigation and increase flooding risks. Photosynthesis is affected by the presence of high levels of turbidity by blocking light penetration and hence causes death of aquatic flora and dissolved oxygen reduction.

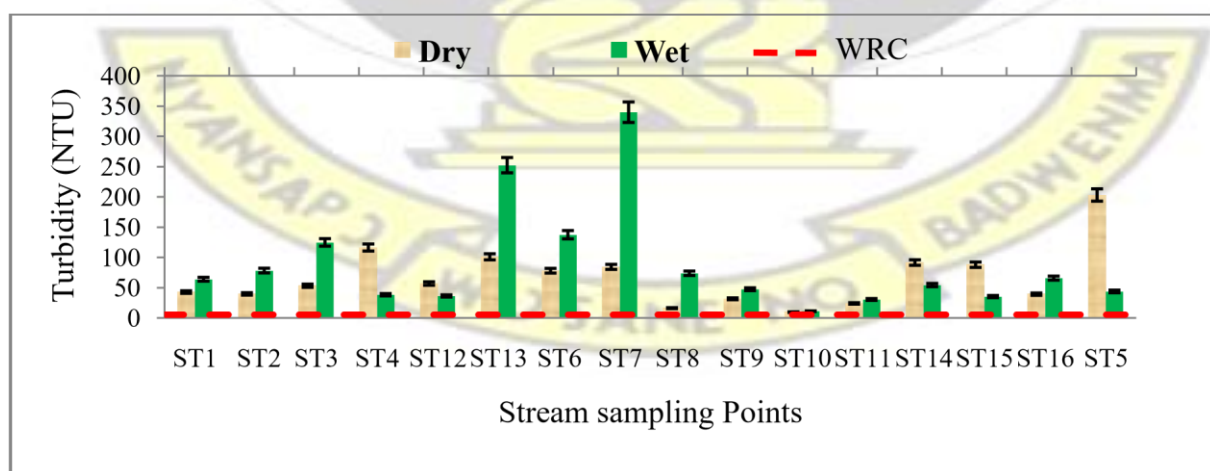


Figure 4.6: Turbidity in the Onukpawahe stream

4.3.7 Total Suspended Solids (TSS)

The concentration of TSS was found ranging from 117 mg/l to 788 mg/l in the wet period and 48 mg/l to 224 mg/l in the dry period (Table 4.1C and D, appendix 2). The high TSS levels during the wet period is due to mixing of higher level of catchment washing through large number of discharges, while dry season showed comparatively low level of TSS (Figure 4.7). The TSS values observed were far higher than the WRC raw water quality guideline “no effect” range of 0–5 mg/l (WRC, 2003). However, the ANOVA ($P = 0.005$, $P < 0.05$) indicates statistically significant differences in the concentration between the sites. The high TSS values observed during the wet season could be due to runoff and serious erosion on the banks along the stream. In addition, the TSS concentrations increased from site ST3, through site ST4 to site ST7 (Figure 4.7) which implicate the industries as a result of the raw material such as spent grains, yeast and dyes from the textiles used for manufacturing processes and also coagulated blood from slaughter house. When such effluents containing high loads of suspended matter are discharged into stream, they increase turbidity and reduce light penetration available for aquatic plants, algae and mosses and has serious health implication.

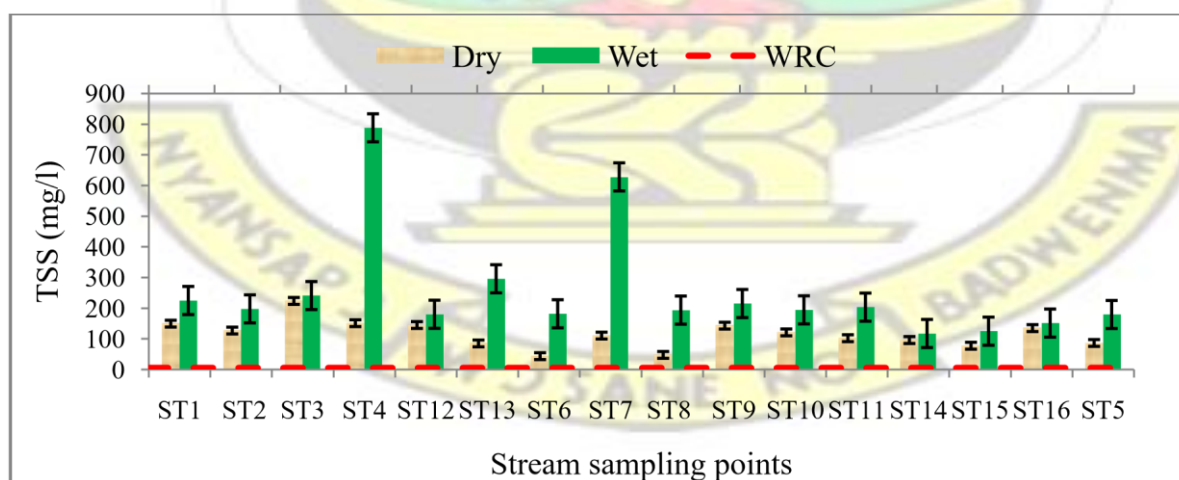


Figure 4.7: TSS measured in the Stream

4.3.8 Nitrate-Nitrogen

The nitrate concentration was found to be between 0.01 and 5.60 mg/l in the wet period and 0.23 mg/l to 7.45 mg/l during the dry period (Table 4.1C and D, Appendix 2). The lowest nitrate concentration was obtained at site ST8 and the highest nitrate level was obtained at site ST12 during the wet period, whereas in the dry season the lowest nitrate concentration value was recorded at site ST14 and the highest at site ST13 (Figure 4.8). The nitrate concentrations in the current study were within the WRC raw water quality guideline “no effect” range of 0–6 mg/l (WRC, 2003) except site ST13 and ST6 which were higher during the dry season. The nitrate concentration varied insignificantly along the sampling site the ANOVA ($P = 0.722$, $P > 0.05$). The high levels of nitrate recorded at the site ST13 in the dry period and site ST12 during the wet periods which are the immediate downstream site of discharge points for a beverage and Textile industries is an indication of pollution load in the effluent from these industries. The high concentration is probably due to the use of food preservatives containing nitrogenous compound and presence of organic pollutants rich in nitrogen content (Walakira, 2011). Ugwu and Wakawa (2012) found that runoff; leaks from manholes, animal waste and wastewater release from industries are the major source nitrate from man. The most essential tool in assessing, sitting and remediating anthropogenic source of nitrate is sequential monitoring of nitrate, when there is high urbanization and lands changed into farm lands (Ugwu and Wakawa, 2012). According to Ipeaiyeda and Onianwa (2011), high levels of nitrates in streams used as source of potable water are associated with methaemoglobinaemia in bottle-fed infants refer to as blue baby syndrome. The elevated level of nitrate in the Onukpawahe stream in the dry season (0.23 - 7.45mg/l) signifies a complete decomposition of proteinaceous matter in the dry period as compared with wet period (Figure 4.8). This nitrate concentration could lead to eutrophication in the stream and consequently influence aquatic life.

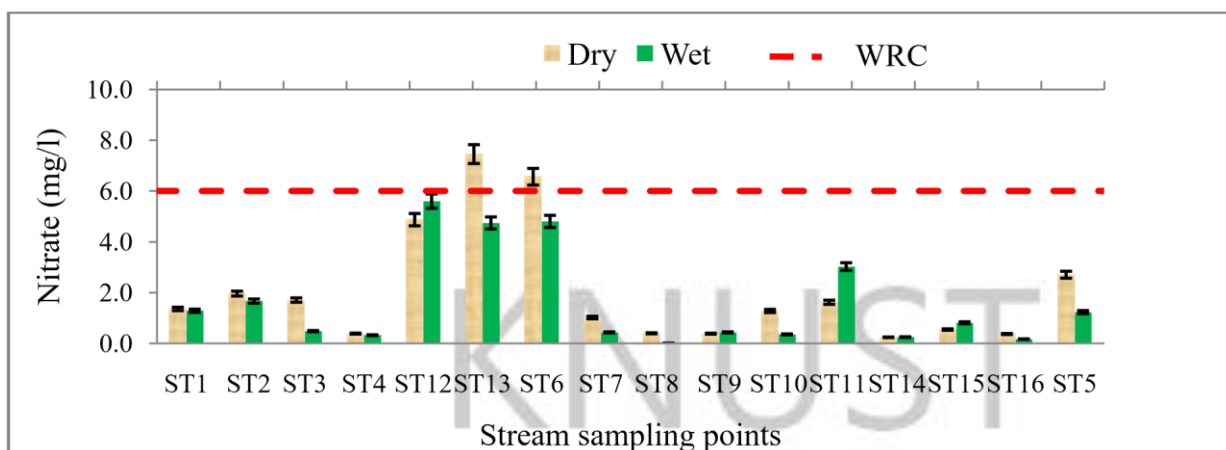


Figure 4.8: Nitrate levels measured in the Stream

4.3.9 Sulphate

The current study revealed the sulphate concentration ranges from 5.53 mg/l to 108 mg/l in the dry period and varied from 0.01 mg/l to 65 mg/l in the wet period (Table 4.1C and D, appendix 2). The lowest sulphate concentration was observed at site ST14 in the dry period which is immediate upstream of the discharge points, whereas the highest concentration of sulphate was obtained at site ST13 for the same period which is at the immediate downstream of wastewater release point (Figure 4.9). Also, in the wet season the lowest sulphate concentration was observed at site ST3 far downstream sampling location, while the highest concentration of sulphate was also observed at site ST13 (Figure 4.9). The sulphate concentration of the stream water samples in the current study were within the WRC raw water quality guideline values the “no effect” range of 0–200 mg/l (WRC, 2003). The concentration between the sites was found to be statistically significant (ANOVA, $P = 0.006$, $p < 0.05$). The sharp rise in the concentration of sulphate recorded at the site ST13 the immediate downstream site of the discharge points of the beverage and textile industries is an indication of discharge of industrial effluent into the stream by these industries. According to Fawaz et al. (2013), the major sources of sulphate in stream are rock weathering, volcanoes, and human activities such as mining, industrial effluent discharge, and fossil fuel combustion process. The bioaccumulation of the inorganic substances such as sulphate (5.35 mg/l to 108 mg/l), could result in reduction in the level of dissolved

oxygen and proliferation of nutrient (Sirohi *et al.*, 2014). This condition could be a threat to aquatic organisms and plants. In similar work by Hasan and Miah (2014), indicated that when sulphate concentration in water reach a level of 1000 mg/l, it create laxative effects and causes gastrointestinal irritation.

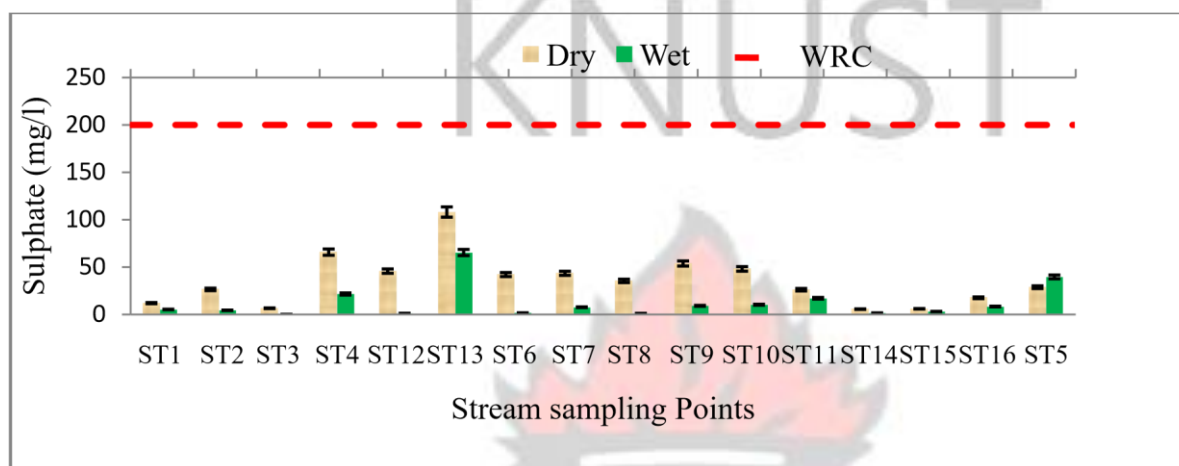


Figure 4.9: Sulphate levels measured in the Onukpawahe stream

4.3.10 Phosphate

The current study indicates that the concentrations of phosphate in the stream samples vary between 17.93 mg/l and 99.70 mg/l in the dry season and 2.5 mg/l and 83 mg/l in the wet season (Table 4.1C and D, Appendix 2). The highest value of phosphate concentration in the dry period was obtained at site ST13 (Figure 4.10), whereas the minimum value was recorded at site ST8 (Figure 4.10). During the wet period the maximum concentration was obtained at site ST 2 and least was observed at site ST8 (Figure 4.10). The ANOVA ($p = 0.081$, $P > 0.05$) shows that the phosphate concentration differences between stations was not statistically significant. The phosphate concentrations observed were above the WRC raw water quality guideline values the “no effect” range of 0–2 mg/l (WRC, 2003). This is an indication of pollution loads in the Onukpawahe stream. The lowest mean phosphate level of 20 mg/l was recorded upstream. Relatively high levels of phosphate downstream with mean phosphate level of 48 mg/l is due to the discharge of effluent with high phosphate concentration into the stream. The results of the phosphate level in the study (Onukpawahe stream) which is a tributary of the Sakumonu

Lagoon were very high compared to the results of similar studies by Agbemehia (2013) and Nartey *et al.* (2012) in Sakumonu Lagoon which ranges from 1.97 mg/l to 4.72 mg/l and from 0.01 mg/l to 2.90 mg/l respectively. The high concentrations of phosphate in the mid-stream where most of the industries are located is an indication of some level of pollution by these industries which could lead to eutrophication condition which may deplete the dissolved oxygen in the stream causing danger to aquatic life (Fawaz *et al.*, 2013). According to Nartey *et al.* (2012) industrial effluent, fertilizer runoff, domestic effluents particularly those containing detergents, are the main reasons of high phosphate levels in surface water such as streams, rivers and lakes. In similar research by Fakayode (2005) revealed that the major sources of phosphate in the effluent were from phosphoric acid, phosphate and detergent used for cleaning purposes in the canteens of most of the industries.

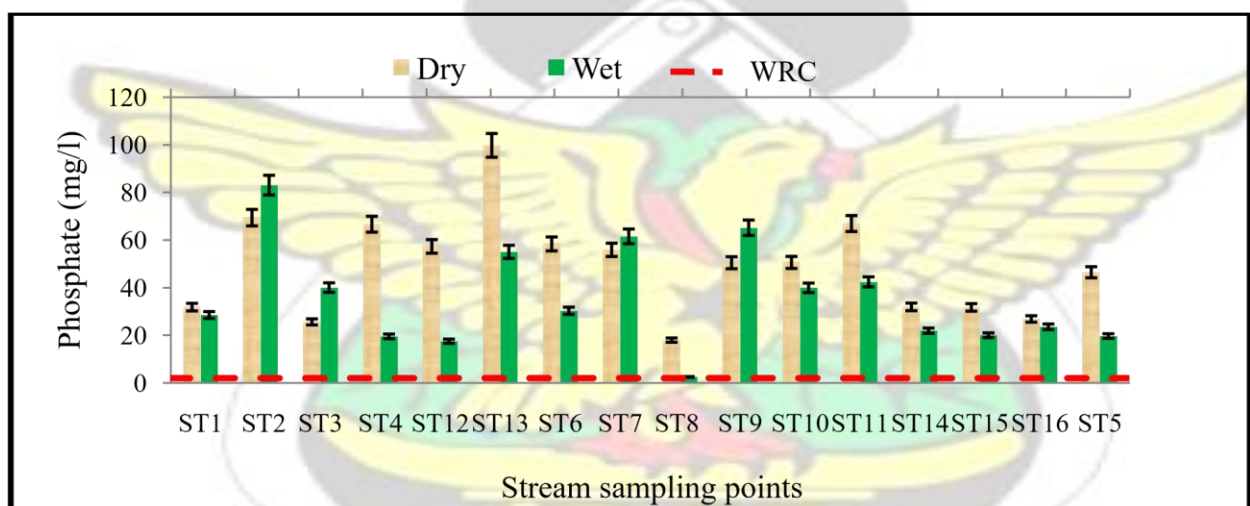


Figure 4.10: Phosphate concentration in the stream

4.3.11 Ammonia

The concentrations of ammonia-nitrogen in the stream samples were between 0.01 mg/l and 0.90 mg/l in the dry season (Figure 4.11), while it was between 0.01mg/l and 16 mg/l in the wet period (Figure 4.11). The maximum level of ammonia was observed at site ST6 (Downstream of slaughter house and biscuit plant) and lowest was at site ST5 (upstream) in the dry period, whereas in the wet period the lowest level was observed at site ST5 and the highest was at site

ST1(Figure 4.11) . The ammonia –nitrogen recorded throughout the study period were within the WRC raw water quality guideline values the “no effect” range of 0–1 mg/l (WRC, 2003) except for site ST1 which value was observed to be 16mg/l in the wet period. The ANOVA ($P = 0.350$, $P > 0.05$) indicates that the difference between the sites interns of concentrations were statistically insignificant. The concentration of ammonia in the stream could be attributed to ammonium bicarbonate which is used as part of the biscuit production process which effluent is discharged into the Onukpawahe stream (Ipeaiyeda and Onianwa, 2011). However, the high ammonia concentration recorded at site ST1 (16mg/l) during the wet period could be attributed to discharge from residential facilities, runoff from vegetable farms and wastewater from factories which contain high nutrients levels and could cause growth of algae bloom resulting in eutrophication in the Onukpawahe Stream.

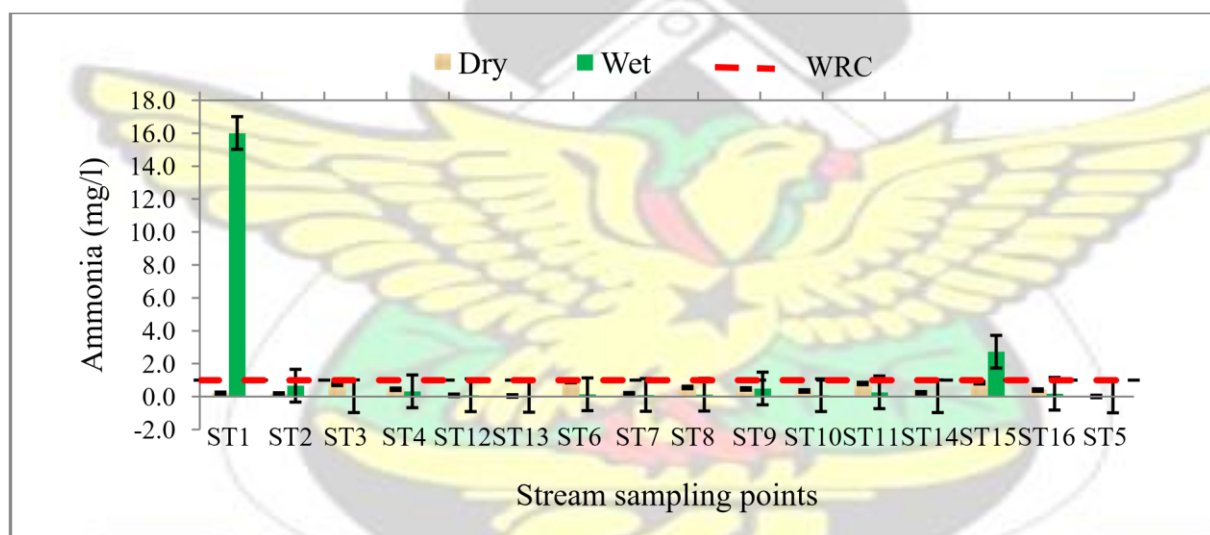


Figure 4.11: Ammonia concentration in the Onukpawahe stream

4.3.12 Colour

According to Walakira (2011) colours in natural waters could be attributed to decay of organic substances and discharge of certain waste. The recorded colour ranges from 66 TCU at site ST16 (upstream station) to 783 TCU at site ST4 in the dry period, whereas in the wet period it ranges from 32.5 TCU at site ST8 to 297 TCU at site ST4 (Table 4.1C and D, Appendix 2). The

observed colour in the stream was far higher than the WRC raw water quality guideline “no effect” range of 0–15 TCU (WRC, 2003), (Figure 4.12). The difference in concentrations between sites were not statistically significant (ANOVA, $P = 0.056$, $P > 0.05$). The low recorded colour values upstream and the high values downstream throughout the entire period is an indication of the relative state of the downstream water impacted by industrial effluent (Ipeaiyeda and Onianwa, 2011). The change in colour downstream may be as a result of organic dyestuff and organic substances in the industrial effluent discharge by Textile and the Beverage industries. The high colour could interfere with light penetration and affect photosynthesis which could affect aquatic life.

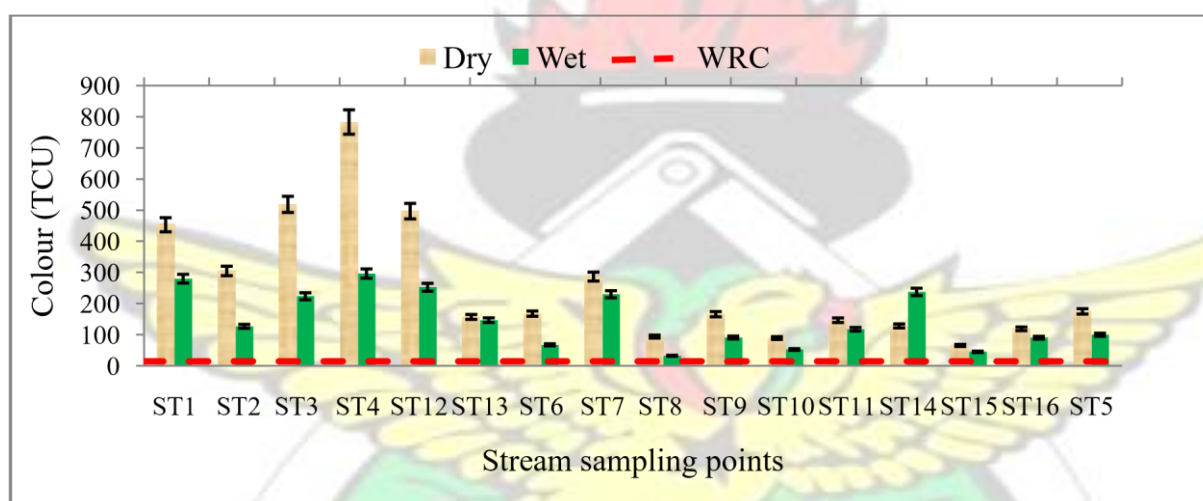


Figure 4.12: Concentration of colour in the Onukpawahe stream

4.3.13 Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand in the stream was between 79 mg/l lowest at site ST16 and 677 mg/l highest at site ST1 (Figure 4.13) in the dry period, whereas in the wet period a lowest of 83 mg/l at site ST14 to the highest of 554 mg/l at site ST1 (Figure 4.13). These observed BOD concentrations were far higher than the WRC raw water quality guideline values the “no effect” range of 0–30 mg/l (WRC, 2003) and this is an indication of pollution of the stream. However, the ANOVA ($p = 0.002$, $p < 0.05$) indicates significant differences between the concentrations of BOD at the sites. The high BOD concentration at these sampling locations

could be attributed to the discharge of industrial effluent with high levels of organic compounds; decay of dead plants and other sources such as runoff from farm lands, and septic tanks leaks. Similar observations were made by Attiogbe *et al.* (2009). According to Monney *et al.* (2013), BOD concentration has direct association with dissolved oxygen levels. The impact of high BOD concentration results in anaerobic conditions which could deplete the dissolved oxygen in the stream and influence an aquatic environment, fatality of fishes, stench and unpleasant disturbances.

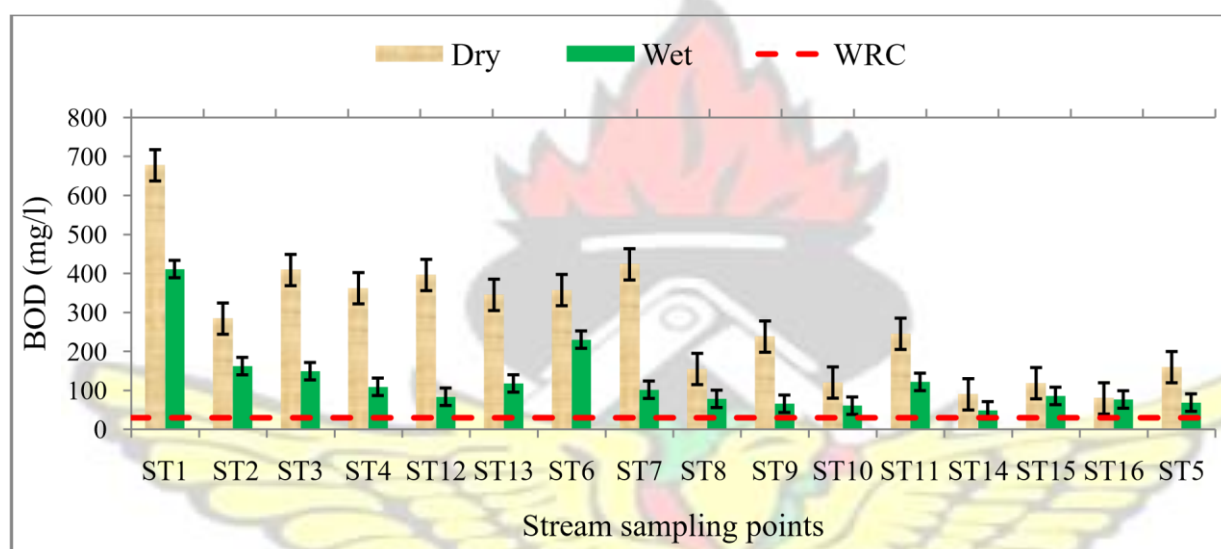


Figure 4.13: BOD level measured in the stream (wet and dry periods)

4.3.14 Chemical Oxygen Demand

The chemical oxygen demand (COD) concentrations of stream water samples were found to be between lowest value of 83 mg/l at site ST14 and highest value of 554 mg/l at site ST1 in the wet period (Figure 4.14,), whilst in the dry period the least was of 119 mg/l at site ST16 and highest of 977 mg/l at site ST1 (Figure 4.14). The observed results were far higher than the WRC raw water quality guideline “no effect” range of 0–75 mg/l (WRC, 2003). Furthermore, differences of COD concentration were statistically significant between sites (ANOVA, $P = 0.002$, $P < 0.05$). The presence of this level of COD is manifestation of pollution of the stream water body due to wide usage of chemical and organic fertilizer and discharge of effluent

including sewerage by anthropogenic activities. The high COD concentration could also be simulated by suspended solids from industries and run-off from farm lands which impaired sunlight, impact on photosynthesis contribute to high turbidity which affects aquatic life. The results of previously published work (Adeogun, 2012; Monney *et al.*, 2013), agree with this and a manifestation of the effects of factory wastewater on the quality of the Onukpawahe stream.

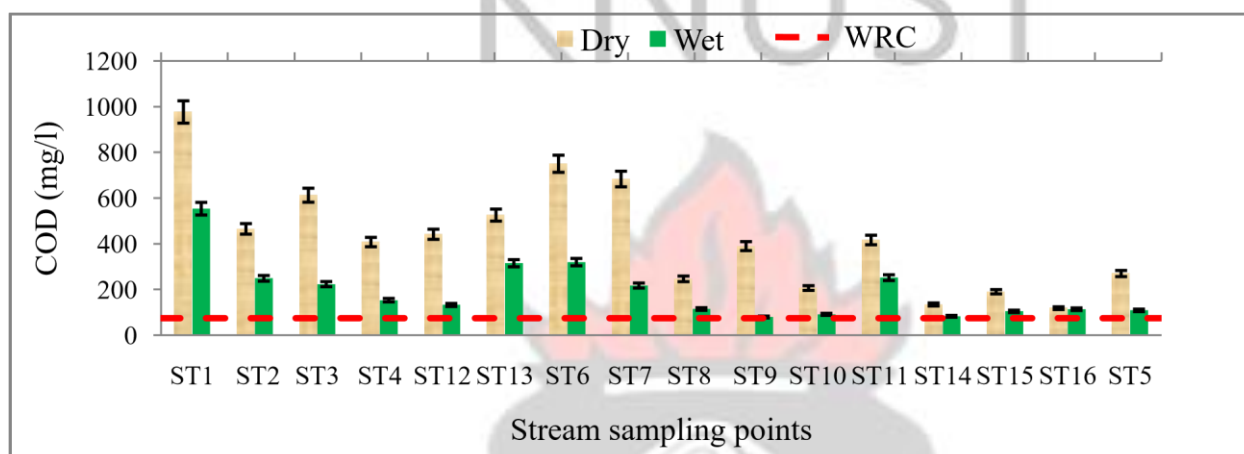


Figure 4.14: COD concentration in the stream samples

4.4 Heavy Metal

The levels of trace metals (Cu, Cr, Zn, Pb, Fe and Cd) were analysed for the sampling sites upstream, mid-stream and downstream of the Onukpawahe Stream (Table 4.1CandD). The sources of the heavy metals from the effluent could probably be from the Textiles, construction and engineering, agrochemical industries and dumping of metal waste into stream bodies.

4.4.1 Copper

The copper level in the stream samples varied from 0.011 mg/l to 2.143 mg/l in dry period and 0.001 mg/l to 1.11 mg/l in the wet period (Table 4.1AandB, appendix 2). The lowest value was recorded at site ST4 and highest was at site ST7 (downstream Site) (Figure 4.15) in the wet period, whereas in the dry period the lowest value was recorded at site ST16 and the highest at site ST7 (Figure 4.15). The values recorded in the current study were within the WRC raw water quality guideline “no effect” range of 0–3 mg/l (WRC, 2003). However, the ANOVA ($P=$

0.142, $P>0.05$) shows that the differences between concentrations of copper upstream and downstream were not significant, while the highest copper concentrations were recorded at the effluent discharge point for most of the sampling period. The high levels of copper observed could be attributed to the discharge of effluent from Textiles, Abattoir and other industries (Kanu *et al*, 2011). Similar report by Hasan and Miah (2014) indicated that copper may incorporate in water from industrial effluents, copper pipes, as well as from pesticides and algacides. Copper is an important and useful substance for flora and fauna survival (Walakira, 2011). Moreover, the harmfulness of copper in human beings is not common but microorganisms in water are at possible risk of exposure to copper (Walakira, 2011). Similar study by Lokhande *et al*. (2011), shows that copper is very harmful to most water plants and animal compared to other trace metals with exception of mercury. Copper impairs the rate of reproduction in water flora and fauna and also retards their development.

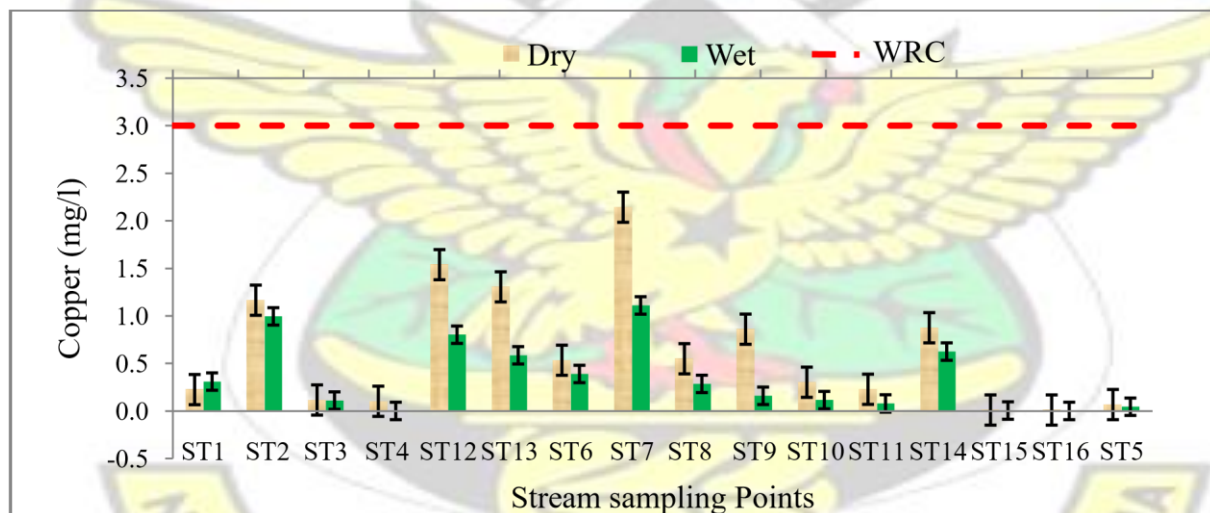


Figure 4.15: Concentration of Copper in the stream

4.4.2 Zinc

The levels of zinc for stream samples varied from <0.001 mg/l to 1.04 mg/l in the wet period, whereas in the dry period it was from 0.007 mg/l to 1.097 mg/l (Table 4.1A and B, appendix 2). The minimum concentration of zinc was recorded at ST1 and highest at site ST13 (Figure

4.16) in wet period due to dilution effect, while the lowest value in the dry period was at site ST 14 (upstream) and the highest at site ST13 (Figure 4.16). From the ANOVA ($p = 0.068$, $p > 0.05$) there were no significant differences between concentrations of zinc between the sites. The highest concentrations of zinc were recorded at the effluent discharge point within sampling period. The concentration of zinc (Zn), measured during the study were within the WRC raw water quality guideline “no effect” range of 0–3 mg/l (WRC, 2003). The high concentration recorded at site ST13 throughout the sampling period is an indication of discharge of effluent from the industries along the Onukpawahe Stream. According to Kanu *et al.* (2011), heavy metals have been associated with the Textile, Abattoir and Beverages industrial effluents.

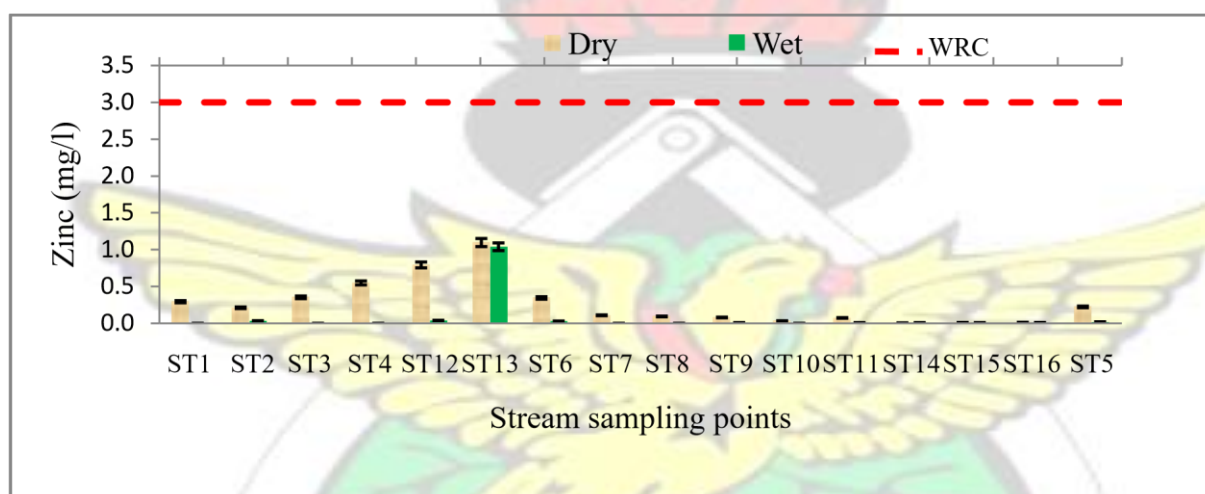


Figure 4.16: Zinc levels measured in the Onukpawahe stream

4.4.3 Cadmium (Cd)

The concentration of Cd varied from 0.001 mg/l to 0.106 mg/l in the wet period and 0.001 mg/l to 0.127 mg/l in dry period (Table 4.1A and B, appendix 2). The minimum value of Cd was observed at site ST15 and the maximum value was observed at site ST4 in the wet period, while in the dry period the minimum was recorded at site ST14 (upstream) and the maximum recorded at site ST4 (Figure 4.17). The concentrations recorded within the period were above the WRC raw water quality guideline “no effect” range of 0–0.1 mg/l (WRC, 2003). However, the ANOVA ($p = 0.016$, $p < 0.05$) indicates that there was a significant change in the concentration

of Cd between sites. These relatively high concentrations of cadmium observed in the Onukpawahe stream during this study is an indication of high levels of contamination attributed to dyestuff and pigments from the effluent discharged by the manufacturing industries. Cadmium as a trace metal can enter streams through galvanized pipes, paint and pigment. According to Lokhande *et al.* (2011), there are limited recorded instances of cadmium poisoning in human beings following consumption of contaminated. Moreover, cadmium has accumulative and toxic effects on the microorganisms and the zooplankton (Walakira, 2011).

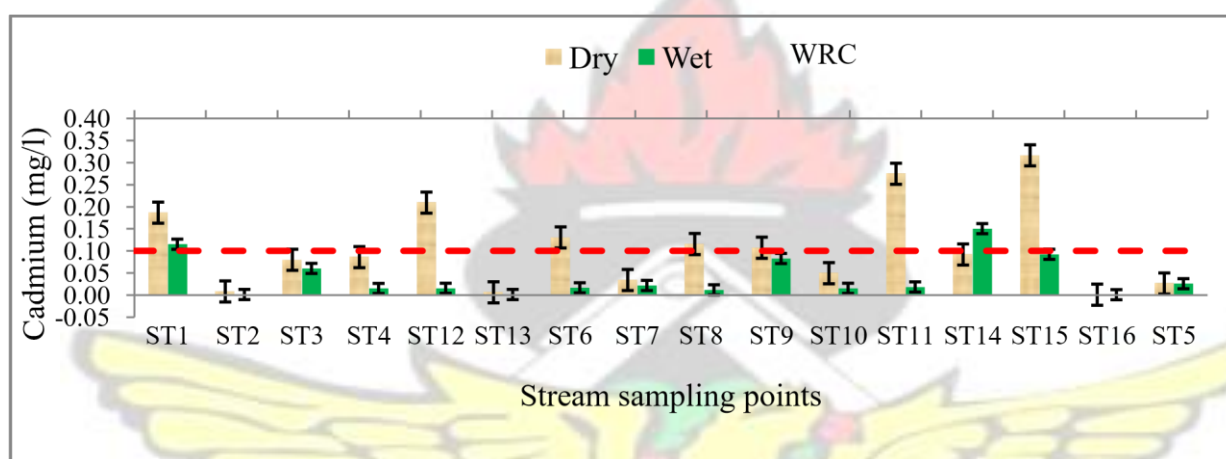


Figure 4.17: Cadmium concentration in the stream samples

4.4.4 Lead

The concentration of lead in the stream samples varied between 0.001 mg/l to 0.328 mg/l in the dry period 0.001 mg/l to 0.307 mg/l in the wet period (Table 4.1C and D, appendix 2). In the dry period the minimum value of lead was observed at site ST16 (upstream) and highest was observed at ST1 (Figure 4.18), whereas lowest concentration in wet period was recorded at ST16 and higher at ST1 (Figure 4.18). The concentrations of lead recorded in this study were within the WRC raw water quality guideline “no effect” range of 0–0.1 mg/l (WRC, 2003) except site ST1 and ST3. Moreover, the ANOVA ($p = 0.68$, $p < 0.05$), indicates insignificant differences in lead concentration between sites. The observed high lead concentration in the downstream and discharge point could be attributed to discharge of effluent from industries

containing paints and dyes material, building materials and gasoline. This contaminated water is used for irrigating vegetables and other food crops along the Onukpawahe Stream because of its high nutrient contents and demand. Trace metals bioaccumulate in the vegetable and farm produce which has been irrigated with the polluted stream and enters the food chain through consumption to a higher trophic level (Fakayode, 2005). The general public who consume such food or vegetables unknown to them could be exposed to this heavy metal hazards (Lokhande *et al.*, 2011). The toxic effects of lead (Pb) result to an increase in water hardness and reduction in fish because lead (Pb) as a toxic element which accumulates in the skeletal structures.

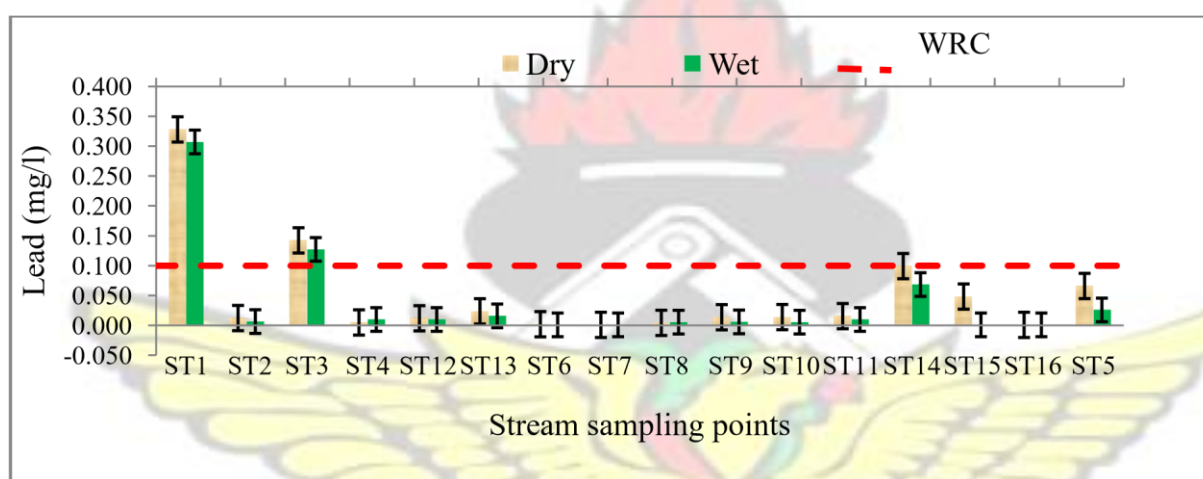


Figure 4. 18: Lead concentration measured in the Onukpawahe stream

4.4.5 Iron

The average iron (Fe) concentration in this current study ranges between a low value of 0.147 mg/l at site ST1 to a high value of 4.50 mg/l at site ST13 in the dry season and low value of 0.030 mg/l at site ST10 in the wet period to a high value of 1.755 mg/l at site ST13 (Table 4.1A and B, Appendix 2). The present study reveals that iron (Fe) concentration in the stream was within the WRC raw water quality guideline “no effect” range of 0–0.1 mg/l (WRC, 2003). The high concentration of iron (Fe) recorded at Site ST13 (Figure 4.19) is an indication of pollution of the stream due to industrial activities especially the Abattoir which is associated with blood which contains a lot of iron. The low value of iron concentration recorded at the sites before the

industrial discharge points as compare to the site after the discharge points has been revealed in other related studies (Adeogun, 2012; Lokhande *et al*, 2011). Trace elements may enter the food chain through accumulation in the aquatic animals when remain as suspended matter or in sediment and as result become toxic to man and aquatic life.

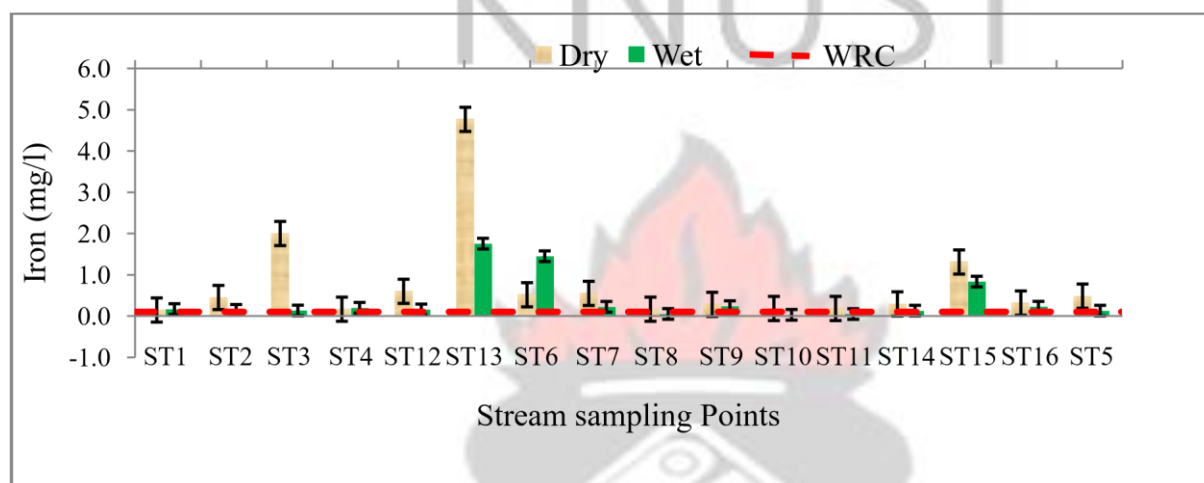


Figure 4.19: Iron concentration measured in Onukpawahe stream

4.4.6 Chromium

The concentration of Chromium (Cr) ranges between a low value of 0.001 mg/l at site St16 (Upstream site) and maximum concentration of 0.127 mg/l at site ST4 in dry period, whereas in the wet period the minimum concentration of 0.001 mg/l was recorded at site ST16 (Upstream) and 0.106 mg/l at site ST4 (Table 4.1A and B, Appendix 2). The ANOVA ($P=0.021$, $P<0.05$) indicates that the differences between the sites were statistically significant. However, the concentrations recorded during the study were within the WRC raw water quality guideline “no effect” range of 0–0.5 mg/l (WRC, 2003). The high level of chromium observed at site ST4 (Figure 4.20) could be attributed to the textile factory effluent which is associated with high levels of chromium, nitrogenous and organic substances depending on the manufacturing procedures use or involved (Hasan and Miah, 2014). A long term exposure of Chromium through drinking contaminated water could cause liver and kidney and nerve tissue

damages. The chromium like other metals is potentially toxic and carcinogenic could equally enter the food chain by bioaccumulation in fishes and other aquatic animals which could lead to health related complications.

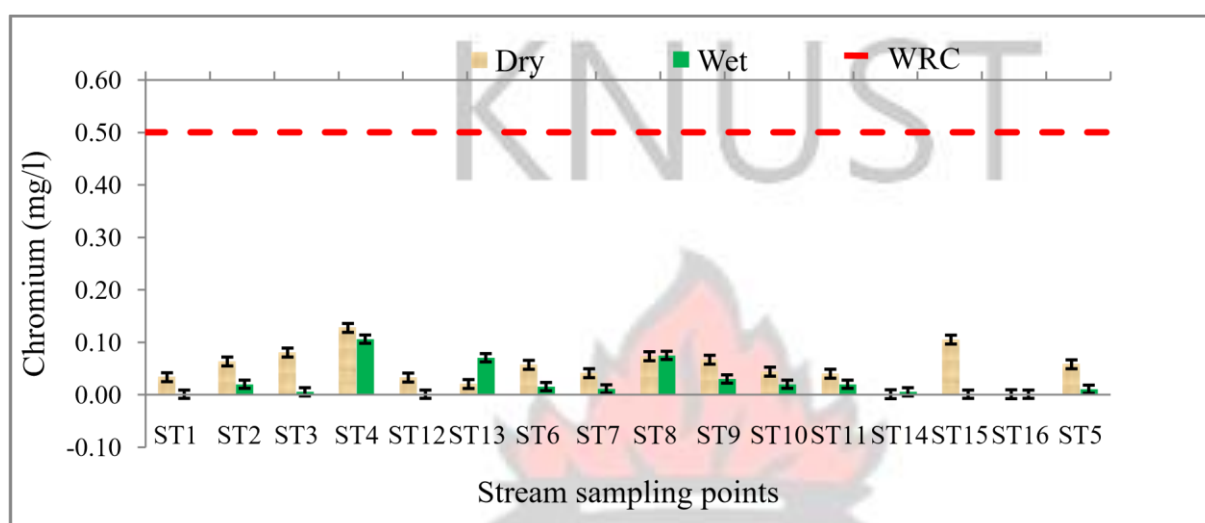


Figure 4.20: Chromium concentration in Onukpawahe stream

4.5 Industrial Effluent Discharge

The concentrations of the physico-chemical parameters measured in the industrial effluent of six (6) selected industries analysed in the dry and wet season are shown in (Table 4.1A and B, Appendix 2).

4.5.1 pH

The mean value of pH observed in the effluents of the industries in the wet period were 5.52 ± 0.59 from industry EF1, 4.725 ± 1.96 from industry EF2, 8.8 ± 0.22 in the effluent of EF3, 5.83 ± 0.21 in the effluent of industry EF4, 6.21 ± 0.18 in the effluent of industry EF5 and 6.61 ± 0.22 in the effluent of industry EF6 (table 4.2A, appendix 2), whereas in the dry period, the pH values recorded were 6.36 ± 0.25 from industry EF1, 5.43 ± 0.22 from industry EF2, 9.2 ± 0.66 in the effluent of EF3, 6.24 ± 0.78 in the effluent of EF4, 5.71 ± 1.55 in the effluent of EF5 and 7.45 ± 0.42 in the effluent from industry EF6 (Table 4.2B, appendix 2). The lowest pH observed in the dry period was in the effluent from industry EF2 (fruit juice and soy milk plant),

whereas the highest pH was observed in the effluent from industry EF3 (Figure 4.21). The low pH (4.73-5.43) in the effluent from industries EF2 (fruit juice and soy milk plant) could be associated with the raw material or reagent such as beans, yeast, fruit concentrate, lactic acid, hydrochloric, nitric, phosphoric and/or sulphuric acids used by this industry which similar observations were made by Phiri *et al.* (2005) and Fakayode (2005). The discharge of this acidic effluent (4.7-5.43) from EF2 has manifested in decreasing pH (5.55-6.63) levels of the stream at site ST3 downstream after the discharge point (Figure 5.1g, Appendix 5). The high pH observed at industry EF3 could be attributed to the pretreatment process of the influents, washing of bottles and cleaning where a lot of caustic materials used as cleaning agents (detergents and NaOH) and additives for food and beverages (e.g. sodium benzoate- C_6H_5COONa and common salt- (NaCl) are used. Similar observation were made by Agyemang *et al.* (2013) and Yeboah (2015) on the Kumasi Coca Cola Plant which indicated that the influence wastewater was alkaline (11.3) and after treatment it dropped to pH (8.9) alkaline. The pH has great impact on the stream quality by affecting the metals solubility, the alkalinity, and hardness of the water. Since most metabolic activities of aquatic organisms depends on pH, the aquatic life is affected (Fakayode, 2005; Ipeaiyeda and Onianwa, 2011).

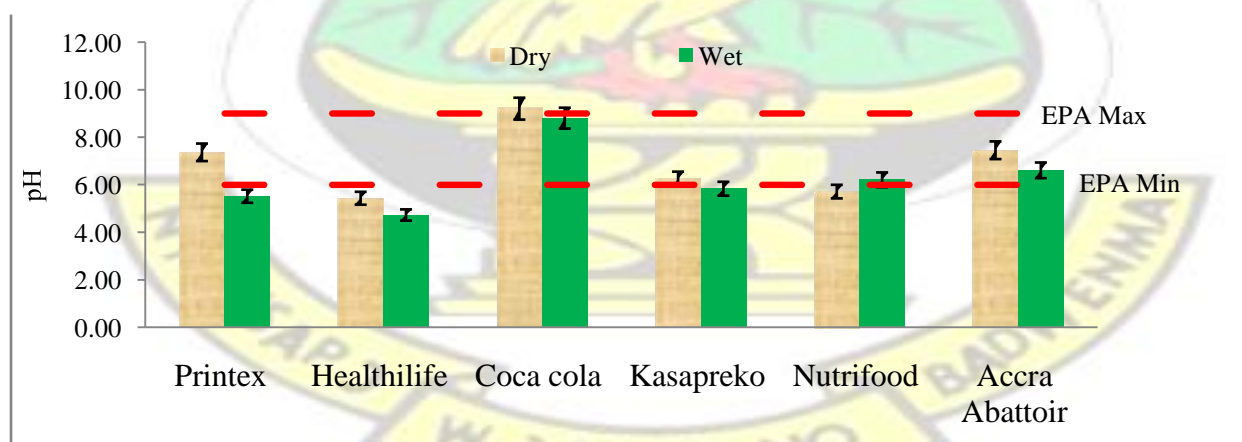


Figure 4.21: pH levels measured in the industrial effluent

4.5.2 Dissolved Oxygen (DO)

The dissolved oxygen (DO) concentration in the industrial effluent of the study area ranged between a low value of 3.89 mg/l in the effluent of industry EF6 (Abattoir) to a high value of 7.67 mg/l in the effluent of industry EF5 (biscuit plant) in the dry period (Table 4.1B, Appendix 2) . In the wet season low value of 4.68 mg/l was observed in the effluent of industry EF6 (Abattoir) and high value of 9.27 mg/l in the effluent of industry EF5 (biscuit) (Table 4.1A, appendix 2). The lowest dissolved oxygen concentration effluent sample was less than 5 mg/l permissible level by Environmental Protection Agency (EPA, 2012), Ghana (Figure 4.22) , before discharge into natural water body . However the high organic load could result in high microbial activity when discharge into the Onukpawahe stream hence cause depletion of the dissolved oxygen in the stream. This implies that no oxygen will be present for aquatic microorganism may be stressed, will suffocate and die. Due to the low dissolved oxygen and high biological oxygen demand (BOD) in the effluent of these industries especially industry EF6, the downstream site ST6 after the discharge point may have impacted in recording low DO (4.01-4.77) (Figure 6.3i, Appendix 6) in both wet and dry periods. The consequence is that there would be no aquatic life at this part of the stream.

Similar findings has been reported by Lokhande *et al.* (2011) and Adeogun (2012).

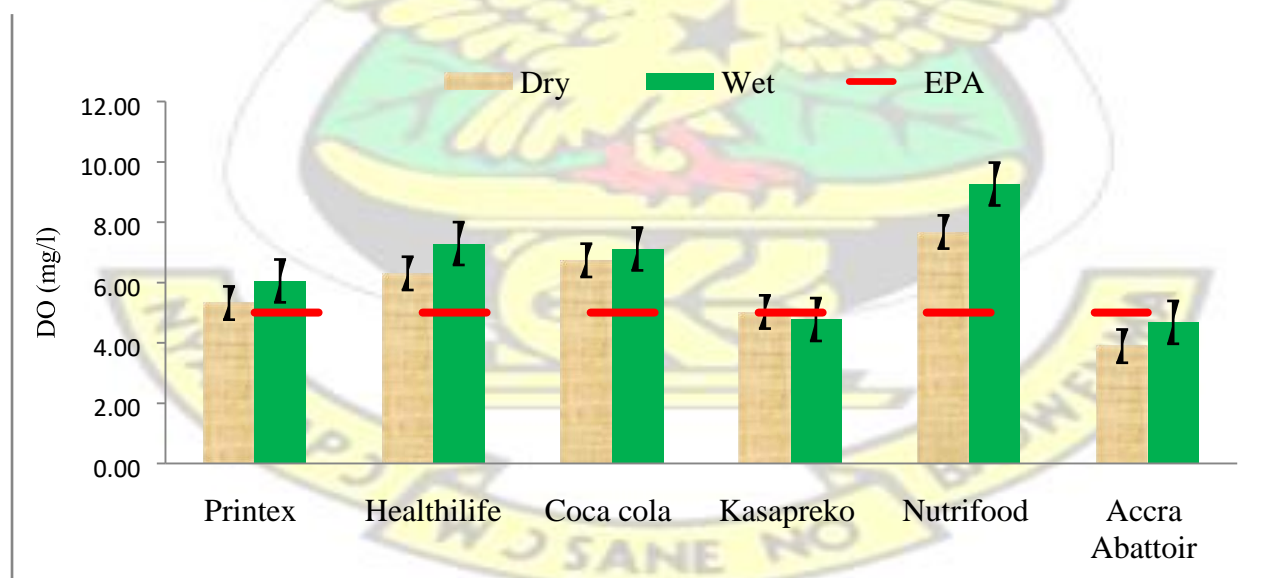


Figure 4.22: DO concentration measured in the effluent samples (wet and dry periods)

4.5.3 Total Dissolved Solids (TDS)

The Total Dissolved concentration recorded in the industrial effluent samples ranged between a low value of 325 ppm in the effluent of industry EF2 to a high value of 3,288 ppm in the effluent of EF6 (Abattoir) in the dry period (Table 4.1B, appendix 2) and a low value of 255 ppm in the effluent of industry EF1 (Textile) to high value of 1,275 ppm in the wet period (Table 4.1A, Appendix 2). The values observed in the industrial effluent in wet period were within EPA effluent quality guideline value of 1000 ppm (EPA, 2012) except for EF6 and EF2, whereas in the dry period the value were within the effluent quality guideline value of 1000 ppm with a exception of effluent from industries EF6, EF3 and EF1(Figure 4.23). The effluent samples from industry EF6 (Abattoir) and EF3 (beverage) were relatively characterized with high level of TDS. The high TDS levels in effluent could be attributed to partly digested food in the gut of slaughtered animals which usually contain nitrogenous substance (Adeogun, 2012) and inorganic solids such as chloride, nitrate, and phosphate anions (Monney *et al.*,2013). The discharge of this industrial wastewater from EF6 for example has led to high levels of TDS and TSS at site ST6 (2,503 ppm -1,275 ppm) downstream of EF6, (Figure 6.3b, appendix 6) as compare to upstream site ST7 (852 ppm 1262 ppm). Fakayode (2005) in a related study found that high TDS is due to the presence of solid ions in the form of chloride, phosphate, sulphate and some trace metals in the wastewater. The microorganisms in the Onukpawahe stream can be negatively affected by this high level of TDS.

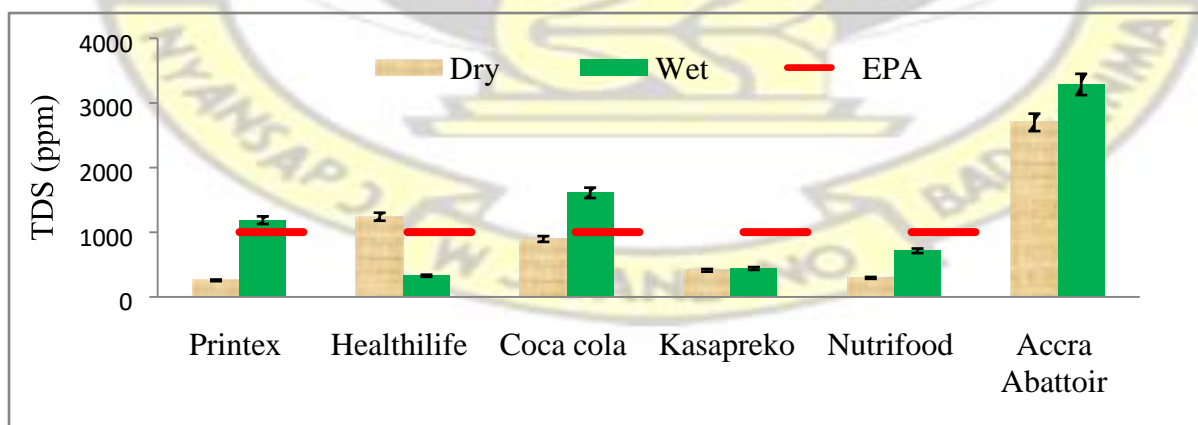


Figure 4.23: TDS concentration measure in the effluent samples in wet and dry periods

4.5.4 Electrical Conductivity (EC)

The current study has revealed that the conductivity values range from a low value of 459 $\mu\text{S}/\text{cm}$ in the effluent of industry EF5 (biscuit plant) to a high value of 5,425 $\mu\text{S}/\text{cm}$ in the effluent of industry EF6 (Abattoir) (Table 4.2 A and B). Generally the values were above the EPA effluent guideline values of 1500 $\mu\text{S}/\text{cm}$ before discharge into natural water body (EPA, 2012). The high conductivity level in these industrial effluents could be attributed to presence of ions which include chlorides, phosphates and nitrates (Fakayode, 2005). Also nitrogen substances in a form of partly digested diet in the gut of slaughtered animals (Adeogun, 2011) and spent yeast, dyes and organic waste. These high level discharges into the Onukpawahe stream are adversely affecting the humans and aquatic habitat. Comparing the various discharge points to the upstream site and the downstream site shows significant differences between the upstream and the downstream after discharge point on the entire site where industries are located and along all the tributaries into which they are discharging into (Figure 5.3c, appendix 5).

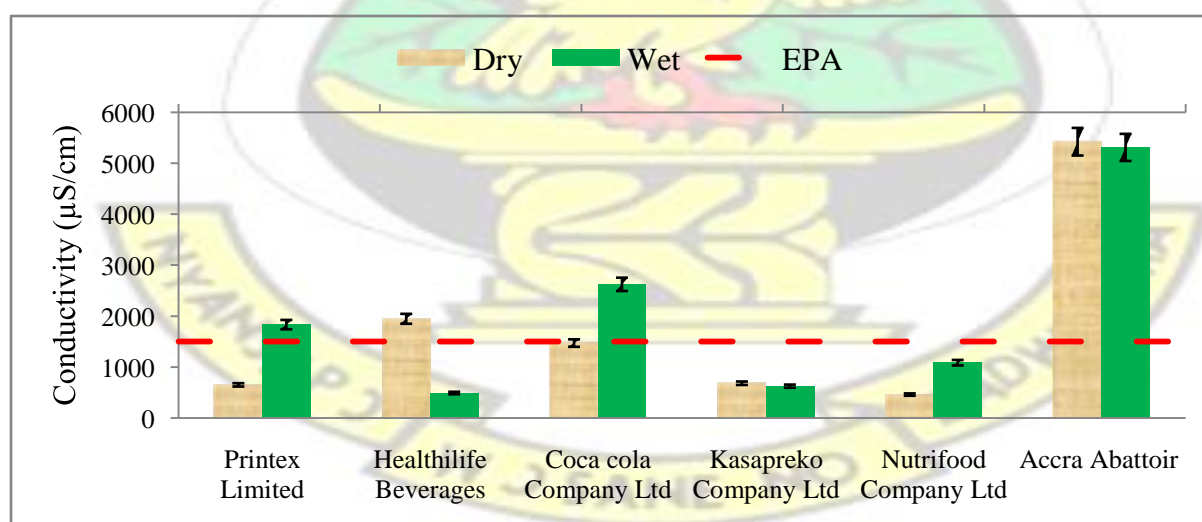


Figure 4.24: Conductivity concentration measured in the Industrial effluents

4.5.5 Turbidity

Turbidity is an important water quality parameter. It indicates cloudiness or clarity of water as result of organic or suspended material in the water (Kemker, 2015). The observed turbidity from the current study were from a low value of 13 NTU in the effluent of the industry EF3 (beverage) to high concentration value of 630 NTU in the effluent of industry EF6 (Abattoir) (Table 4.1 A and B). The turbidity observed in the effluent of these industries was above the EPA effluent quality guideline value of 75 NTU (Figure 4.25). Moreover, from the ANOVA ($p = 0.97$, $p > 0.05$) indicate that for all the tributaries (upstream and downstream of each discharge points) showed no significant differences between the various sampling sites. Figures 5c, 5.2n, 5.3d and 5.4c, Appendix 5 show that there was a lower turbidity level at upstream location before the discharge points of the various industries than the levels at downstream location just after the discharge points, where the industries are discharging their effluent. These values suggest that the Onukpawahe stream has been polluted downstream after each discharge point. The highest value recorded in the effluent of EF6 (Abattoir) may be attributed to organic wastes, animal waste and presence of soil particles. This could be the reason why TSS, TDS, conductivity, BOD and COD were all increasing at the downstream site ST6 of the discharge point of industry EF6 (Abattoir) (Figures 5.1c, 5.2n, 5.3d and 5.4c, Appendix 5). Increased turbidity reduces light penetration needed for photosynthesis by some aquatic life (Monney *et al.*, 2013 ; Sirohi *et al.*, 2014) When these organic wastes are continuously discharged into the aquatic ecosystem, it may terminate the aquatic life and emanate foul odour into the environment.

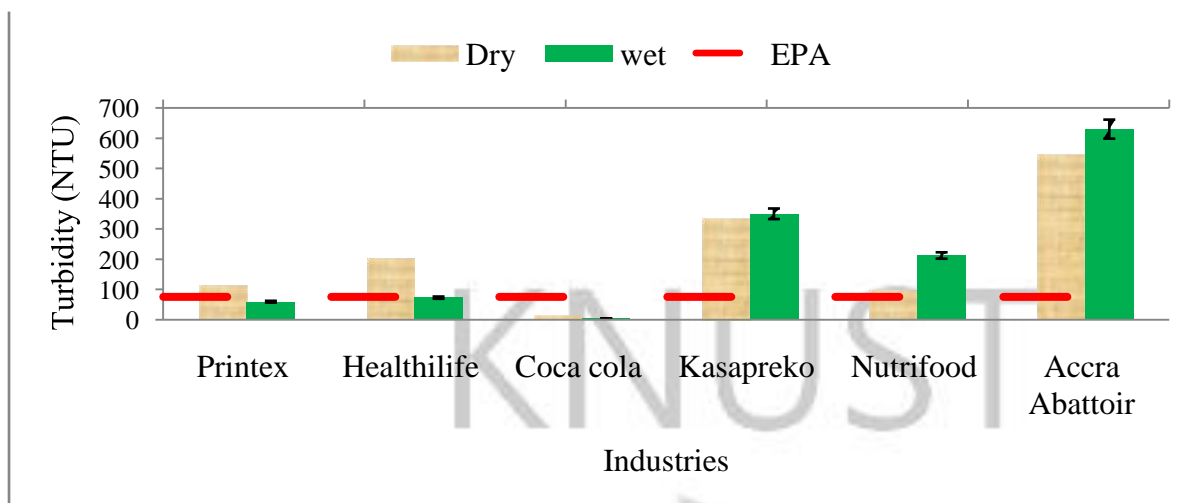


Figure 4.25 : Turbidity levels measured in the Industrial effluent in wet and dry period

4.5.6 Total Suspended Solids (TSS)

From (table 4.1 A and B, appendix 2) the value of TSS from the effluent were from low of 92 mg/l in the wastewater from industry EF3 (beverage plant) to a high value of 509 mg/l in the effluent of industry EF6 (Abattoir) (Figure 4.26). the observed TSS values were all above the EPA, Ghana guideline value of 50 mg/l (EPA, 2012) throughout the period (wet and Dry). The study also revealed that the observed TSS values at the downstream sites after the discharge points of the various industries was high indicating an industrial effluent pollution (Figure 5.1e, 5.2p, 5.3e, and 5.4e, appendix 5). There were significant differences between the sites (ANOVA, $P < 0.05$). The high TSS in the industrial effluent could be due to the fact that these effluent usually consist of microbes, degradable substance and plankton from their production processes especially EF6 (Abattoir). Similar research by Diya'uddeen *et al.* (2014) reveals that TSS in River Galma, Zaria Nigeria contains particles such as clay, silt organic and inorganic substances. The impact of TSS are affecting fish feeding and growth, light penetration in water for production food (photosynthesis) and support microbial pollution which are harmful to humans because suspended particle serve as attachment side for bacteria.

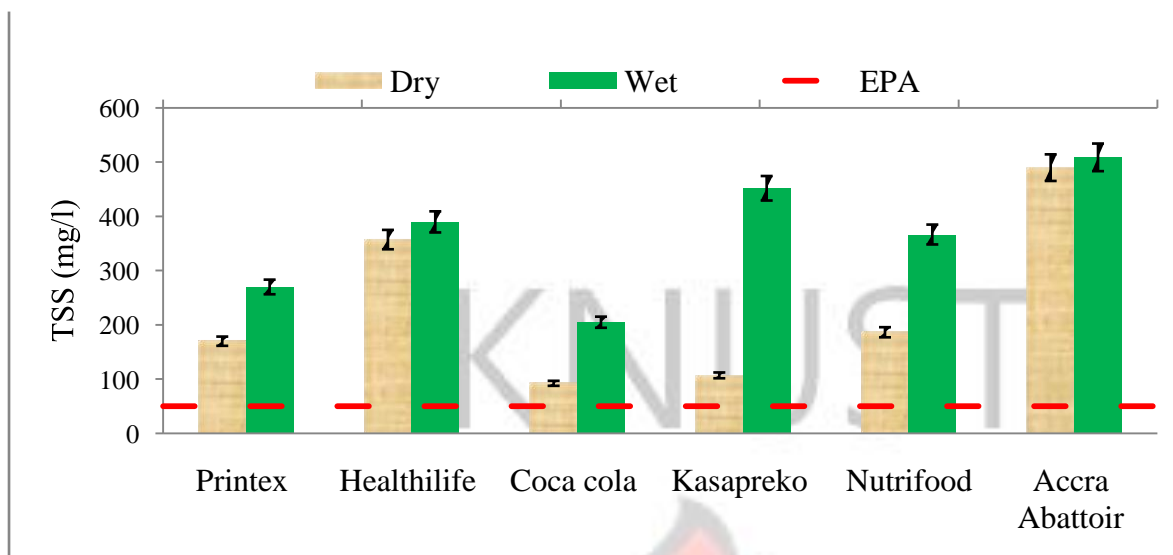


Figure 4.26: TSS concentration measured in the effluent samples (wet and dry periods)

4.5.7 Nitrate-Nitrogen

In the present study, the Nitrate levels in the collected effluent samples varied from a low value of 0.223 mg/l in the wastewater of industry EF2 to a high of 30.9 mg/l in the wastewater of industry EF6 (Table 4.1 A and B, appendix 2). The observed nitrate concentration were within Effluent quality guideline of 10 mg/l by EPA except EF6 (EPA, 2012), (Figure 4.27). From the ANOVA ($p = 0.00$, $p < 0.05$) there were significant difference between the site before and after the discharge points. The concentration of nitrate recorded at the immediate downstream after the discharge point of industries were higher than the upstream on most of the tributaries along the stream in the study area (Figure 5.2(j), Appendix 5). The high levels of nitrate observed at downstream after the point of discharges of effluent implicates industrial wastewater as the main cause of pollution to the stream. The high nitrate level of 30.9 mg/l in effluent of the Abattoir could be attributed nitrogen substances as waste in the form of partly digested food in the gut of slaughtered or process animals such as cattle (Adeogun, 2011). According to Hasan and Miah (2014) nitrate is relatively nontoxic for fish health, except when the concentration of nitrate exceed above 90 mg/l in water. The stream receiving this effluent

loses much of aquatic life and intense consequences due to microbes, oxygen demand load and ecological disturbance.

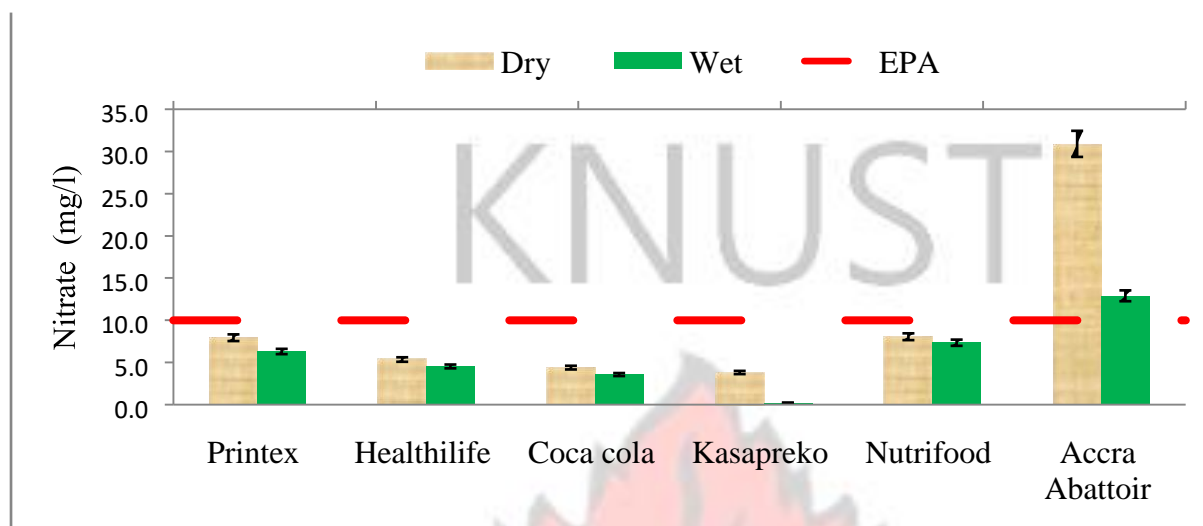


Figure 4.27: Nitrate concentration measured in the industrial effluent (wet and dry season)

4.5.8 Sulphate

The sulphate level was found to be between a low value of 0.54 mg/l in the effluent of industry EF4 (alcoholic beverage) and a high value of 68 mg/l in the effluent of industry EF1 (textile) (Table 4.1A and 4.1B, Appendix 2). The sulphate concentrations in the industrial effluent in the study area were within the EPA acceptable limit of 200 mg/l before discharge into natural water body (Figure 4.28). There was statistically significant between the concentration of sites at upstream and downstream after discharge points (Figure 5.4(j), appendix 5). Fakayode (2005) reported that high concentration of sulphate in the effluent is attributed to raw materials such sulphuric acid and sulphate salts used by most factories. When a high sulphate concentration of 1000 mg/l is discharged into drinking water source it create laxative effects and causes gastrointestinal irritation (Hasan and Miah, 2014). When sulphate and organic element accumulate in the water body due to discharge of these industrial effluent could result in the depletion of dissolved oxygen, eutrophication and therefore influence the life of microorganisms in the water.

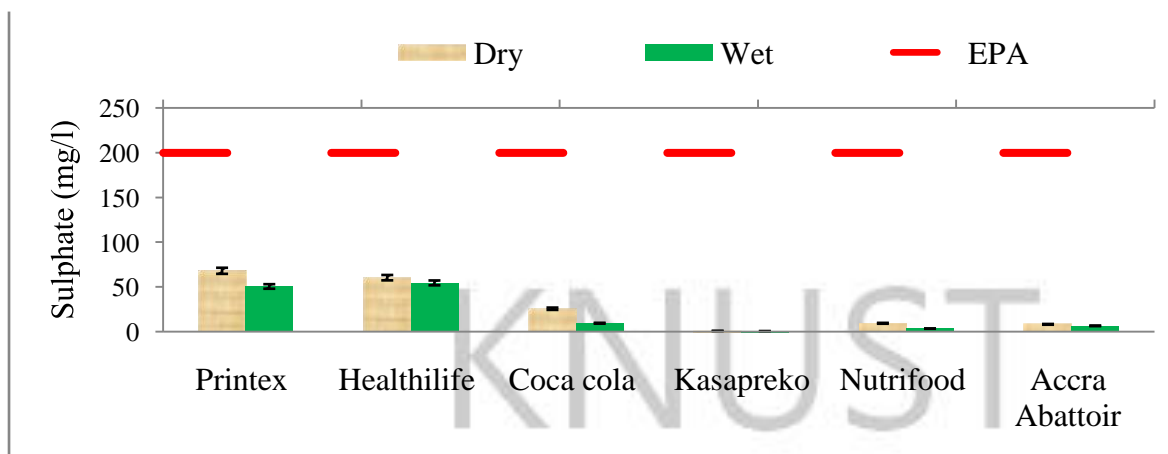


Figure 4.28: Sulphate concentration in the industrial Effluent

4.5.9 Phosphate

The study revealed that the concentrations of phosphate in the industrial effluent samples were between (0.285 mg/l and 0.553 mg/l) in the effluent of industry EF3 (Beverage) in both periods and high value of (24.6 mg/l and 90.83 mg/l) in the effluent of industry EF6 (Abattoir) in both period (Table 4.1A and B, appendix 2). Phosphate in the effluents were above the EPA acceptable limits of 2 mg/l (EPA, 2012) except in the effluents of industries EF1 (0.76 mg/l and 0.795 mg/l) and EF3 (0.553 and 0.285 mg/l) (Figure 4.29). The source of the high levels could be due to the use of phosphate containing substances in the manufacturing process and detergents for washing and cleaning purposes. However, comparing the concentration at the discharged point and the downstream indicates high levels at the downstream of the discharge point which implicates industrial wastewater as the main factor influencing the health of the stream (Figure 5.2e, appendix 5). However the ANOVA ($P = 0.244$ $P > 0.05$) indicates that there is insignificant differences between the concentration at the discharge point and sites at the downstream of the discharge points on all the tributaries. Moreover, high levels of phosphate in contaminated water can leads to difficulties in digestion. Phosphate combining with the available nitrate will easily influence the development of algae and eutrophication process in

the Onukpawahe stream which would increase dissolved oxygen depletion depriving the aquatic life of oxygen and consequently death.

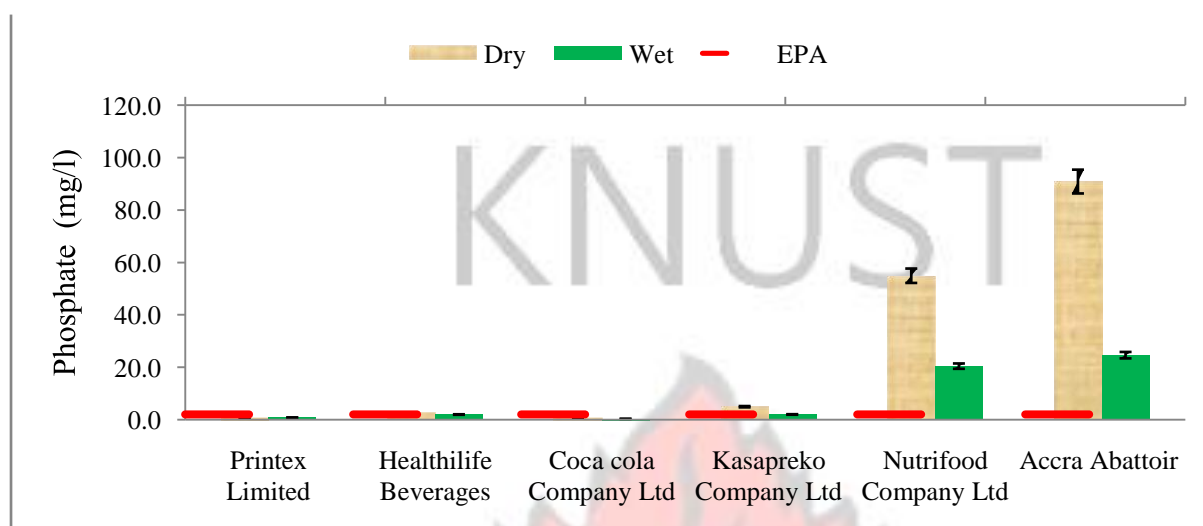


Figure 4.29: Phosphate concentration measured in the Industrial effluent

4.5.10 Ammonia

The concentration of ammonia-nitrogen in the industrial effluent samples were found to be between (0.58 mg/l and 0.28 mg/l) in the effluent of industry EF3 (beverage plant) for both period and high value (5.78 mg/l and 5.07 mg/l in the effluent of EF1 (Textile) for both dry and wet periods (Table 4.1 A and B, Appendix 2). The highest concentration (5.78 mg/l and 5.07 mg/l) was observed in the effluent of industry EF1 (textile) in the wet and dry periods (Figure 4.30). The ammonia –nitrogen in the industrial effluent recorded throughout the study were above the acceptable guideline value of 1 mg/l by EPA (EPA, 2012) except in the effluent of industry EF2 (beverage plant) value observed to be (0.58 mg/l and 0.28 mg/l) in the wet and dry periods. The ANOVA ($P = 0.116$, $P > 0.05$) shows insignificant differences between the upstream and downstream after the discharge point of the industries along the various tributaries (Figure 5.2n, Appendix 5). The high ammonia concentration in the factories wastewater could be attributed to raw materials such as ammonium bicarbonate for manufacturing of biscuits (Ipeaiyeda and Onianwa, 2011), animal waste and organic load such as dyes for textile

production. The high ammonia levels in the effluent discharged may cause algal outbreaks (eutrophication) in Onukpawahe Stream. The algal die and decompose and consequently depleting the dissolved oxygen in the stream and this could result in the death of aquatic flora and fauna releasing odour into environment. Similar observation have been reported by Fawaz *et al.* (2013).

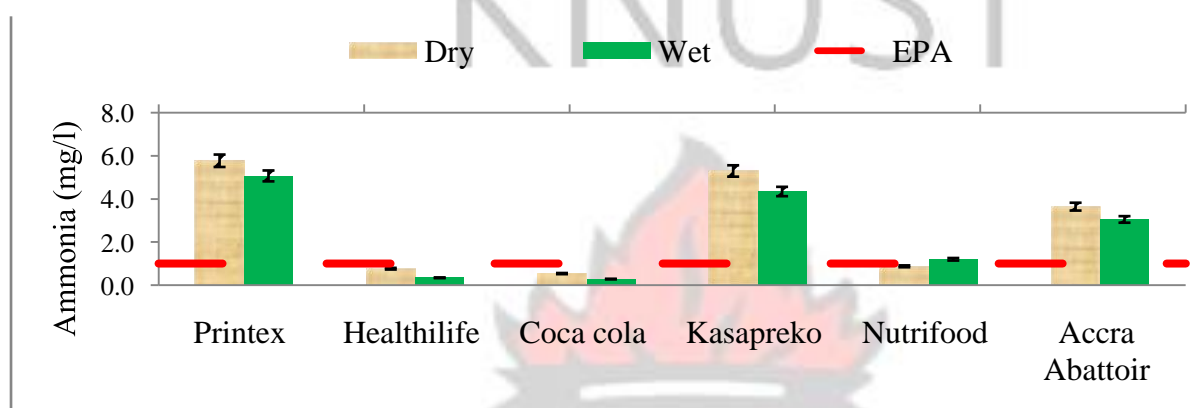


Figure 4.30: Ammonia concentration measured in the industrial effluent

4.5.11 Colour

The colour observed in the industrial effluent ranges from a low 149 TCU in the effluent of industry EF3 (beverage plant) to a high of 1,310 TCU in the effluent of industry EF6 (slaughter house) in the dry period, whereas from a low of 95 TCU in the effluent of EF5 (fruit juice) to high of 465 TCU in the effluent of industry EF1 (textile) (Table 4.1 A and B, appendix 2). The concentrations recorded were above the EPA effluent quality guideline value of 200 TCU (EPA 2012), (Figure 4.31). However, the difference in concentrations between the Upstream and the downstream of each discharging point were statistically significant ANOVA ($P = 0.02$, $P < 0.05$) (Figure 5.3f, 5.4d, Appendix 5). The low colour values upstream and the high values downstream after discharge point is an indication of relatively impacted state of the downstream water by industrial effluent (Ipeaiyeda and Onianwa, 2011). The high colour could be as a result of blood animal waste, organic dyestuff, organic substances in the effluent of these industries. The high colour could interfere with light penetration and affect photosynthesis these cause danger and death of aquatic life.

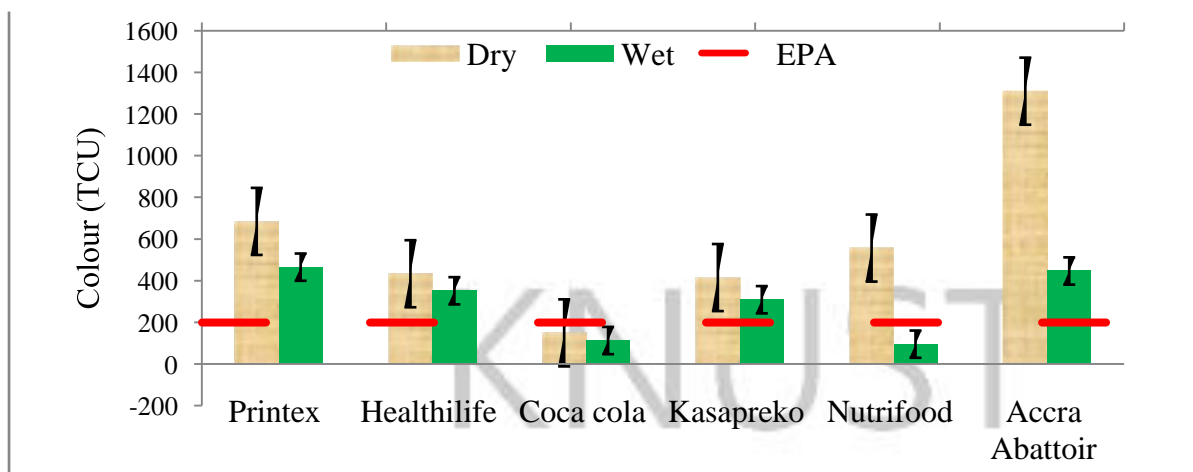


Figure 4.31: Colour in the Industrial effluent

4.5.12 Biochemical Oxygen Demand (BOD)

The Biochemical Oxygen Demand concentration in the industrial effluent ranged from a low of 166 mg/l in the effluent of industry EF1 (textile) to a high of 14,838 mg/l in the effluent of industry EF6 (Slaughter house) (Table 4.1 A and 4.1B, Appendix 2). These observed BOD concentration were above the EPA guideline value of 50 mg/l (EPA, 2012), (Figure 4.32) and this is an indication of a possible pollution of the water bodies by these industries when their effluents are discharged into Onukpawahe. The concentration difference between the upstream and downstream after each discharge point of the industries was statistically significant, ANOVA, ($P = 0.008$, $P < 0.05$). The high BOD concentration in the effluent means the industries produce greater quantities of degradable organic ad nutrients in the effluents likely dyes and animal waste. Similar observations were by (Phiri *et al.*, 2005).

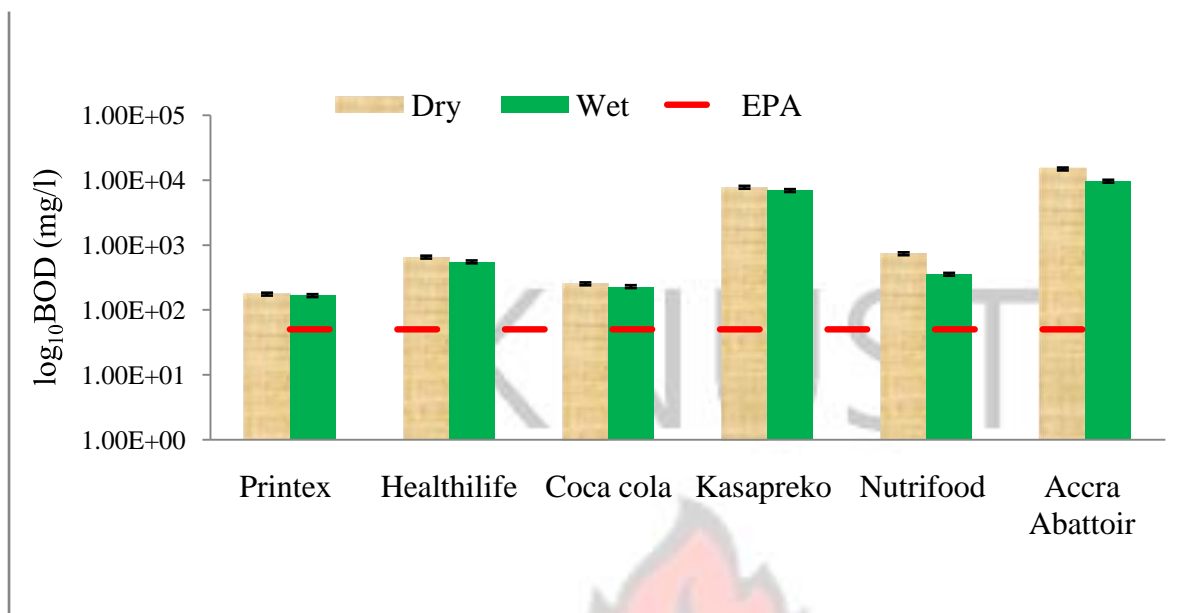


Figure 4.32: BOD concentration measured in effluent samples for (wet and dry period)

4.5.13 Chemical Oxygen Demand (COD)

The chemical oxygen demand concentrations in the industrial effluent samples were between a least value of 218 mg/l in the wastewater of industry EF3 (Beverage) and the highest of 14,436 mg/l in the effluent of EF6 (Abattoir) in the wet period (Table 4.1 A, Appendix 2), whilst in the dry period least 119 mg/l at site ST16 and high 977 mg/l at site ST1 (Table 4.1B, Appendix 2). However, the observed results were above the acceptable limit of 250 mg/l by EPA (EPA, 2012), (Figure 4.33). Moreover, the differences of COD concentration were statistically significant between the upstream and downstream after each discharge point of the industries along various tributaries (ANOVA, $P = 0.004$, $P < 0.05$) (Figures 5.1b, 5.2r, 5.3g, appendix 5). The presence of high level of COD especially EF6 (slaughter house) is an indication of production of wide range of waste such as coagulated blood, chemicals used in production process, organic, inorganic substances and dyestuff by these Industries. The high COD concentration is simulated by suspended solids from these industries and also from the wet process from textile which could impair light penetration, oxygen depletion and leads to

reduction in photosynthesis in plant. The fauna and flora are being influenced. Similar results are reported in previously published work (Adeogun, 2012; Monney *et al.*, 2013) .

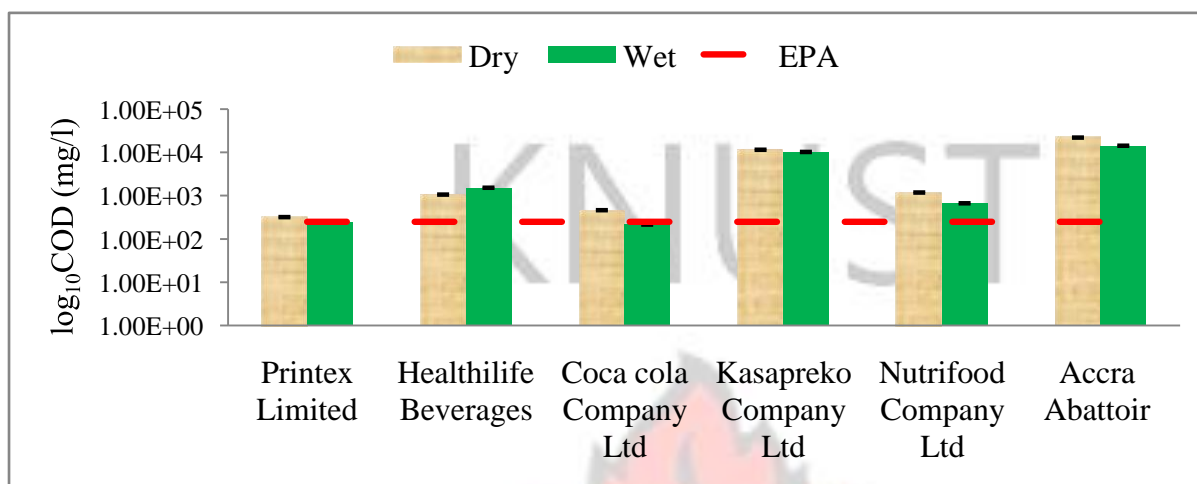


Figure 4.33: COD concentration measured in the effluent samples in wet and dry period

4.6 Heavy Metal

The concentration trace metals (Cu, Cr, Zn, Pb, Fe and Cd) were analysed at the six selected industries in the Tema Motorway industrial area which discharge their effluent into the Onukpawahe Stream (Table 4.1 A and 4.1B, Appendix 2).

4.6.1 Copper (Cu)

The concentration of copper in the industrial wastewater samples varied from a low value of 0.117 mg/l in the wastewater of industry EF2 (Fruit juice) to high value of 5.007 mg/l in the effluent of industry EF6 (Abattoir) in the dry period and low of 0.01 mg/l in the wastewater of industry EF3 (beverage) to high value of 5.89 mg/l in the effluent of industry EF6 (Abattoir) in the wet period (Table 4.1 A and 4.1B, Appendix 2). The values recorded in the current study were within the EPA guideline value of 5.0 mg/l (EPA 2012) except in the effluent of the industry EF6 (Slaughter house)(figure 4.34). The differences between concentrations of copper were found to be significant (ANOVA, $P = 0.002$, $P < 0.05$) comparing the upstream and the downstream after each discharge point along the tributaries (Figures 5.3r, appendix 5). The high concentration of copper observed is an indication that effluent from these industries especially

the Textiles and Abattoir contains a lot of metallic substances. Ubwa *et al.*(2013) found that the various parts of cattle such as muscles, blood, liver, kidney, viscera and hair contain trace metals. However, the existence of excess copper can cause liver and kidney damage, stomach and intestinal irritation. Moreover, it is rare in human but water aquatic organisms are potentially at risk from copper exposure (Walakira, 2011). Similar research by Lokhande *et al.* (2011) reported that copper is very harmful to fauna and flora than other trace metals with the exception of mercury. It retards the rate of reproduction in fauna and flora and impedes their maturation.



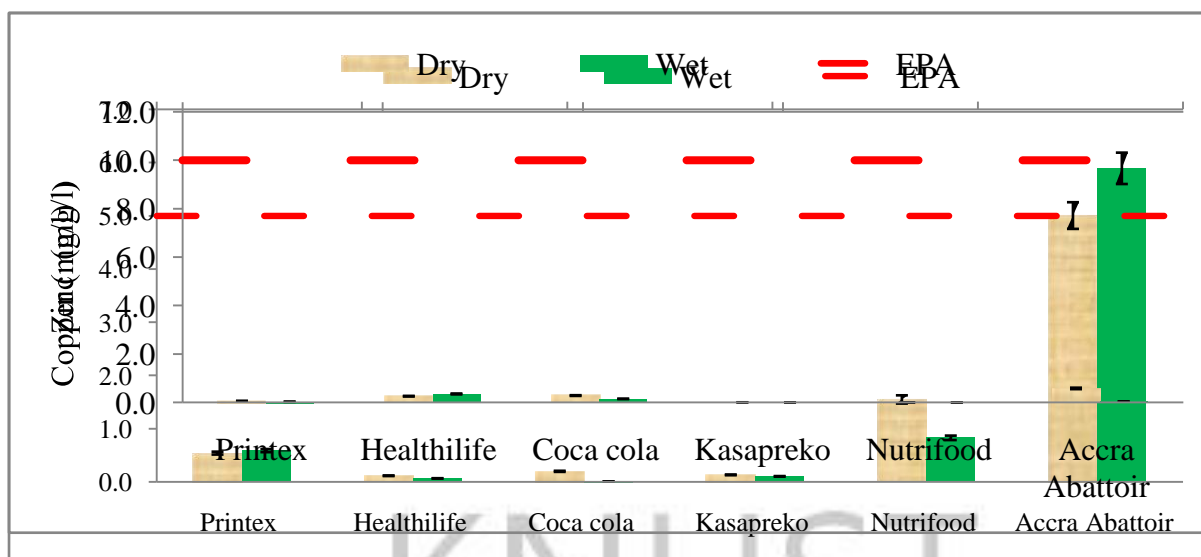


Figure 4.34: Copper concentration measured in the industrial effluent

4.6.2 Zinc (Zn)

The concentration of Zinc in the industrial effluent samples varied from low of <0.001 mg/l in the effluent of EF5 to 0.354 mg/l in the effluent of industry EF2 (beverage) in wet period and 0.004 mg/l in EF5 to 0.581 mg/l in effluent of EF6 (slaughter house) in the dry period (Table 4.1A and B, appendix 2). The concentrations of Zinc, measured during the study were within the effluent quality guideline value of 10 mg/l by Environmental protection Agency (EPA, 2012), (Figure 4.35). According to Kanu *et al.* (2011) the effluents from textile factory have been found to contain trace metals due to the nature of processes, production operation and the characteristics associated with its effluent.

Figure 4.35: Zinc Concentration measured in the Industrial effluent

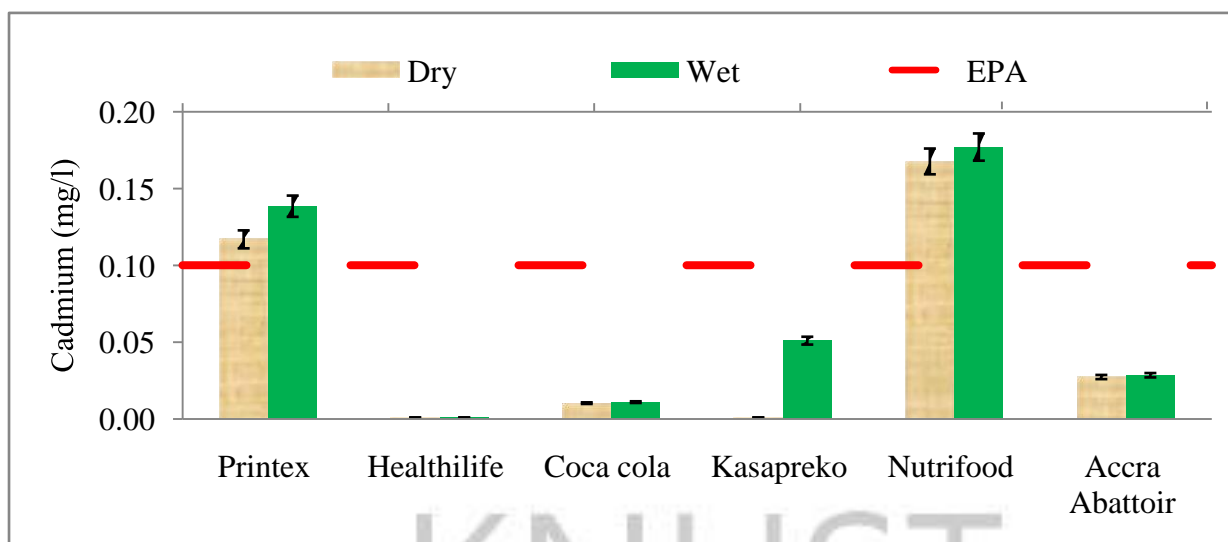
4.6.3 Cadmium (Cd)

The cadmium concentration in the industrial wastewater varied from <0.001 mg/l in the wastewater of industry EFF2 to a high value of 0.168 mg/l in the effluent of industry EF5 in the wet period and <0.001 mg/l in the effluent of EF2 to high of 0.17 mg/l in the wastewater of

industry EFF5 in the dry period (Table 4.1A and 4.1B). The values of cadmium recorded were within the guideline values of 0.1 mg/l by EPA, Ghana (EPA, 2012) except industries EF1 (Textile) and EF5 (biscuit) with concentration of (0.117 mg/l and 0.139 mg/l) and (0.168 mg/l and 0.177 mg/l) respectively (Figure 4.36). The impact of this high concentration is shown in the comparison of the upstream and the downstream after the discharge point which shows that the difference in concentration was statistically significant (ANOVA, $P < 0.05$). The relatively high concentrations observed in the effluent of EF1 (Textiles Industry) could be attributed to gasoline, pigments and dyestuffs from the raw material used in the manufacturing process. According to Lokhande *et al.* (2011) there are few recorded instances of cadmium poisoning in human beings following consumption of contaminated fishes. Walakira (2011) found that cadmium has cumulative and highly toxic effects in all its chemical forms.

Figure 4.36: Concentration of cadmium measured in the industrial effluent samples (wet and Dry)

4.6.4 Lead



The lead concentration in the industrial effluent were between 0.014 mg/l in the effluent of EF4 to high value 0.524 mg/l in effluent of EF1 (textile) in the dry period and 0.001 mg/l to 0.307 mg/l in wet period (table 4.1A and 4.1B, Appendix 2). The dry period observed a low value of 0.02 mg/l in the effluent of EF3 and high of 0.553 mg/l in the effluent of EFF1. The concentrations of lead observed were within EPA, Ghana, and effluent quality guideline value of 0.1 mg/l (EPA, 2012) except industry EF1 (Textile plant) with (0.524 mg/l and 0.553 mg/l), (Figure 4.37). Moreover comparing the upstream and downstream sites after the discharge points of each industry, there was significant difference in the lead concentration between sites (ANOVA, $P = 0.000$ $P < 0.05$) (Figure 5.1r, Appendix 5). The observed high concentration of lead in the effluent of EF1 (Textile) could be due to the raw materials containing paints and dyestuff material and gasoline use by this industry. This effluent discharged into the Onukpawahe stream is used for growing various types of vegetable and other farming activities because of its high nutrient contents. These trace

metals could easily bioaccumulate in the vegetables irrigated with the polluted stream and eventually enter the food chain through consumption (Fakayode, 2005). These food vegetables general could lead to heavy metal hazard such as ulceration and cancer. Lokhande *et al.* (2011) found that at concentration of 0.1 mg/l -10 mg/l lead has acute toxicity in invertebrates.

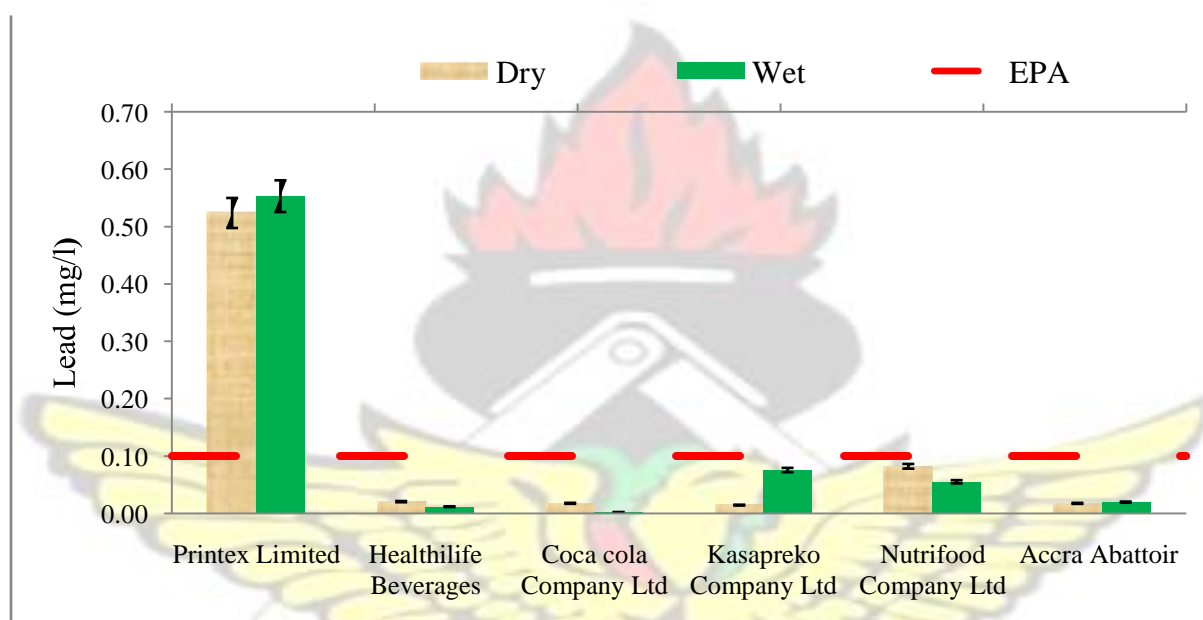


Figure 4.37: Lead concentration measured in the industrial effluent

4.6.5 Iron

The average iron (Fe) concentration in this current study ranges between low value of (0.08 mg/l and <0.01 mg/l) in the effluent of industry EF4 in both seasons and high value of (2.897 mg/l and 0.875 mg/l) in the effluent of industry EF6 (Abattoir) (Tables 4.1 A and 4.1B, Appendix 2). The present study reveals that iron (Fe) concentration in the industrial effluents were within the permissible limit of 10 mg/l (Figure 4.38) by Environmental Protection Agency, Ghana (EPA, 2012). The high levels of iron recorded in the effluent of industry EF6 (Abattoir) could be attributed to animal waste since iron has been found to be an important nutrient for the proper performance of all living things or organisms. According to Ubwa *et al.* (2013) most

organs of animals (Cattle) has been found to contain trace metal and hence abattoir effluent will contain some of these trace metals. However, there was no significant differences between the concentration of iron (Fe) observed at upstream with the corresponding level downstream after the discharge point of each industry (ANOVA, $P = 0.47$, $P > 0.05$) as depicted by (Figure 5.2 k, appendix 5). Microorganism easily accumulates trace elements through contaminated sediments and enters the food chain which could impact negatively on the health of human beings.

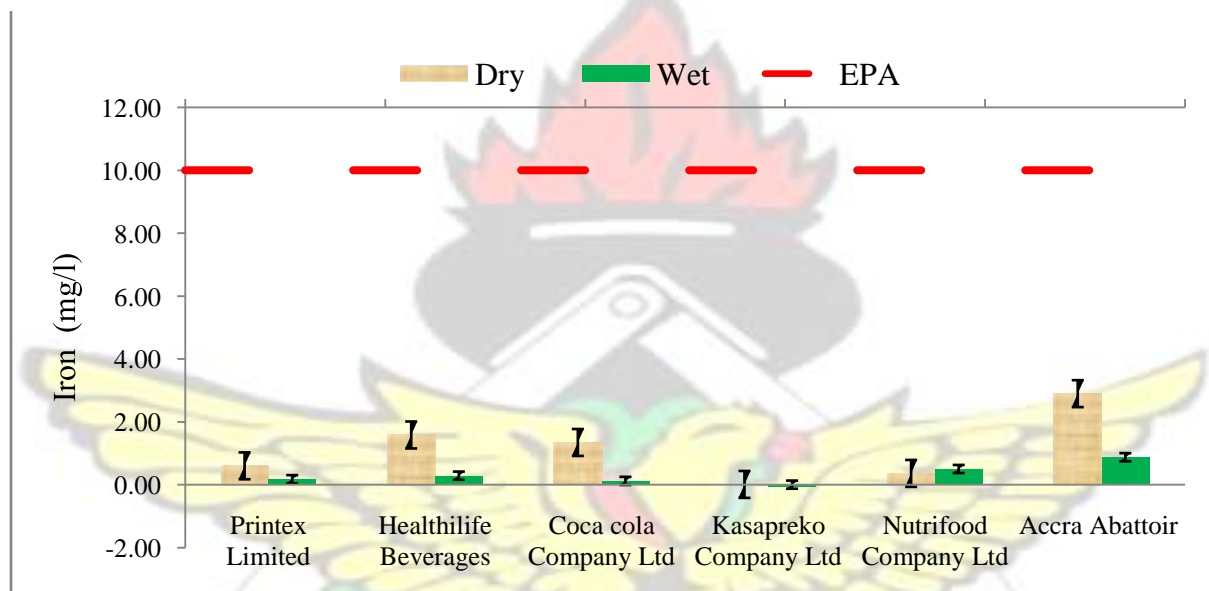


Figure 4.38: Iron concentration measured in the industrial effluent

4.6.6 Chromium

The concentration of Chromium (Cr) found in the industrial effluent range between a low value of (<0.01 mg/l and 0.05 mg/l) in the effluent of EF3 (beverage) in both seasons and a high value of (5.59 mg/l and 7.21 mg/l) in the effluent of industry EF4 (alcoholic beverage) (Table 4.1A and 4.1B, Appendix 2). However, the concentrations recorded during the investigation were above the permissible levels of 0.5 mg/l (Figure 4.39) by Environmental Protection Agency (EPA), Ghana (EPA, 2012). The ANOVA ($P = 0.021$, $P < 0.05$) shows statistically significant difference between the upstream and the downstream after the discharge point of each industry. The high level of chromium observed in the effluent could be attributed to the dyestuff, , organic

substances, chlorinated solvent which may contain some levels of chromium base on the manufacturing process (Hasan and Miah, 2014). Chromium like other metals are potentially toxic and carcinogenic, could equally enter the food chain by bioaccumulation in fishes and other aquatic animals which may leads to health problems in man Lokhande *et al.* (2011)

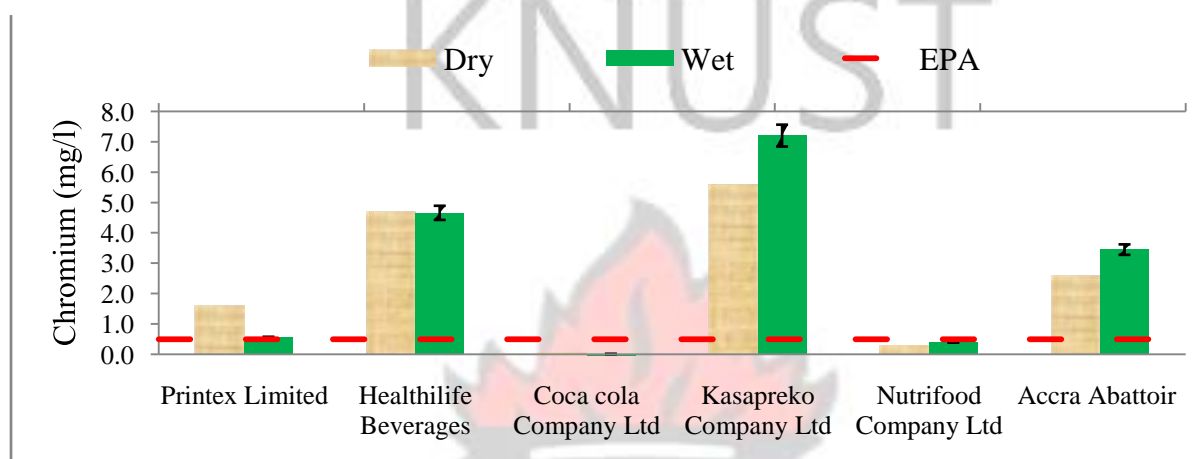


Figure 4.39: Chromium concentration measured in the industrial effluent

4.7 Microbiology

4.7.1 Total and Faecal Coliforms

The Total Coliform (TC) and Faecal Coliform(FC) levels in the stream water samples were found to be between low of 433 counts/100ml at site ST6 and high value of 1.46×10^5 counts/100 ml at site ST6 in both dry and wet season (Table 4.1 G, Appendix 2), whereas in the industrial effluent samples a low value of 867 MPN/100 ml in effluent of industry EF3 (beverage) and a high value of 2.73×10^5 MPN/100 ml in the effluent of industry EF6 (Abattoir) (Table 4.1H, Appendix 2). Moreover, the high coliform levels were recorded at site ST6 which receives high amounts of effluents containing high level of faecal matter from the EF6-slaughter house (Abattoir) and the effluent from Abattoir also recorded the highest faecal coliform (Figure 4.41 and 4.42). The coliform concentration found in industrial effluent could be attributed to the large amount of organic substances which enhance the growth of these bacteria. The ANOVA ($p < 0.05$) indicates significant differences between upstream and

downstream sites after each discharge point. Furthermore, the total and faecal coliform levels in the stream were far higher than WRC raw water quality guideline „no effects“ range of 0-5 and 0 counts/100 ml (WRC, 2003) respectively. However, the faecal and total coliform levels in the effluent samples in the current study exceeded the EPA permissible limit of 400 MPN/100 ml (EPA, 2012) except in the industry EF3 (Coca Cola Company) and stream sampling sites ST14 and ST15 (Figure 4.40,4.41 and 4.42). The presence of high Total and Faecal Coliforms, is an indication of the presence of microbial nutrients which would enhance the after-growth of bacteria which could pose significant and increasing risk of infectious disease transmission (Mosley *et al.*, 2005).

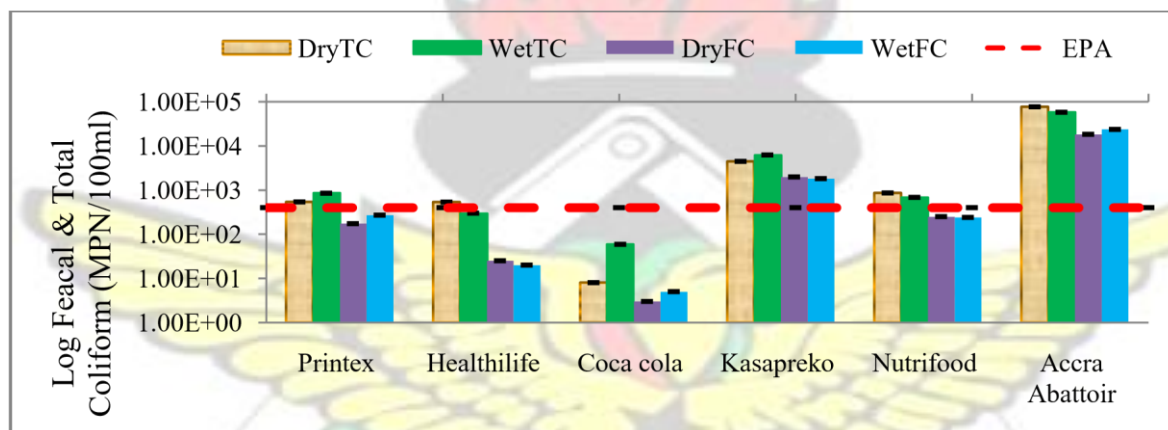


Figure 4.40: Total and Faecal Coliform in effluent samples for wet and dry period

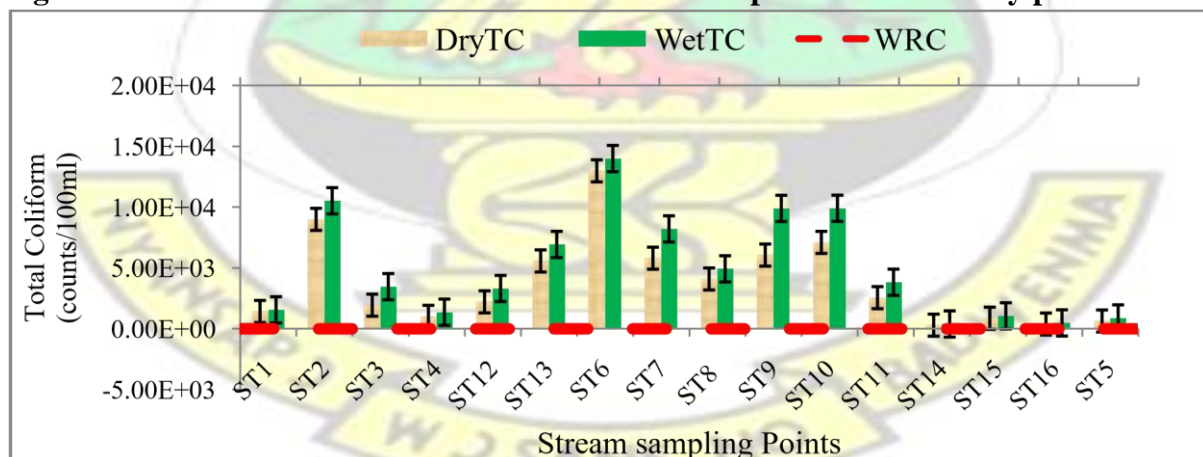


Figure 4.41: Total Coliform in stream samples for wet and dry period.

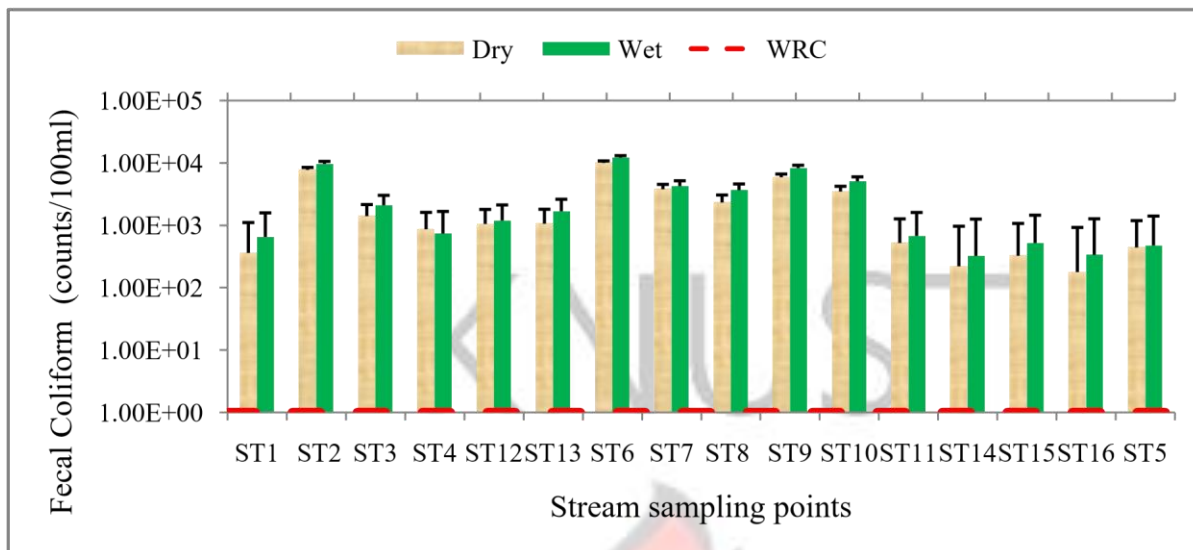


Figure 4.42: Faecal Coliform in stream samples for wet and dry periods

4.8 Water Quality Index

Water quality Index was used to assess the quality of the Onukpawahe Stream and estimate to what extend industries located within the study area has impacted on it. According to (Srivastava and Kumar, 2013) the WQI is the most common tool used in all water quality methods. Nine (9) parameters were used in the calculation of the WQI of Onukpawahe stream. The WQI calculator 1.2 (CCME, 2001), was use in calculating the quality at the various sites on the Onukpawahe stream (Appendix 4). These tests were chosen because they impact significantly on aquatic organisms. The selected parameters are the following; Total Dissolved Solids, Temperatures, Total Phosphate, Nitrate, pH, BOD, COD, Faecal Coliform and Dissolved Oxygen. The WQI for the Onukpawahe stream was calculated to be in the range of 40-63. The WQI indicates that overall quality of the Onukpawahe stream was found to be poor. This shows that the quality of the stream is frequently or always threatened or impaired and deviate more often from desirable levels (Table 4.2, appendix 9).

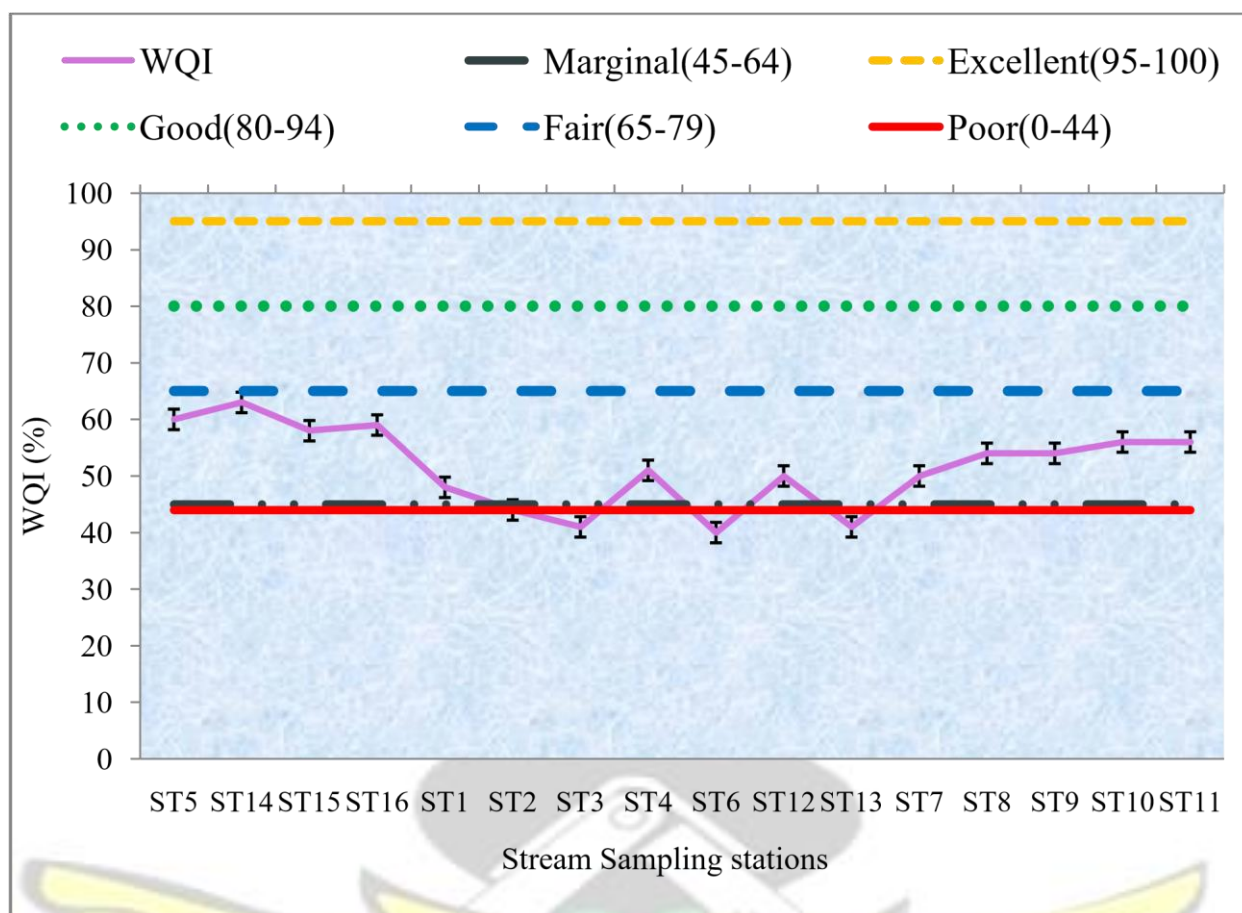


Figure 4.43: Water Quality index of the Onukpawahe Stream

Note: The DO measured in mg/l was converted to Percentage (%) saturation by the use of DO conversion table (Appendix 8) before using it in the WQI Calculator (Table 4.1A, Appendix 4).

Table 4.1: Calculated WQI for the various site

Site	WQI
ST1	48
ST2	44
ST3	41
ST4	51
ST5	60

ST6	40
ST7	50
ST8	54
ST9	54
ST10	56
ST11	56
ST12	53
ST13	41
ST14	63
ST15	58
ST16	59

CHAPTER 5: CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

In general, the analysis from the study has shown clearly that the industries have negative impact on the water quality of the Onukpawahe Streams near the industrial area. This is explained by the fact that there was general increase in concentration of the parameters analysed downstream after each discharge point as compared to upstream sites. Even though, some of

the parameters measured during the study were within the acceptable guideline values by (EPA, 2012), the continued discharge of high concentration effluents into the Onukpawahe stream without any form of effective treatment may result in accumulation of the contaminants. This may affect the lives of human as well as aquatic animals in the Onukpawahe stream.

In view of the findings made in the WQI for the Onukpawahe streams indicate that the overall quality of the Onukpawahe stream is poor. This implies that the water quality (Table 4.3) is under stress and frequently threatened or impaired; conditions usually depart from natural or desirable levels due to high levels of BOD, COD and nutrients discharge into the stream by these industries.

The high loads of toxic chromium, cadmium and copper discharge by these industries especially Accra Abattoir Company Ltd; may result in accumulation in the Onukpawahe Stream and pollute it if proper management and treatment is not taken care of at the source.

This situation is alarming and should alert the regulating Agencies (Environmental Protection Agency and Water Resources Commission) to continuously monitor industrial effluents and surface water bodies and enforce the appropriate pollution laws.

5.2 Recommendations

From the studies and analysis of the collected industrial effluent and the stream water samples the following are being recommended for the implementation and improvement of the quality of Onukpawahe Stream.

- Surface water and industrial effluents quality be monitored on continuous basis.

The monitoring should be conducted collaboratively by the EPA, Water Resources Commission (WRC), Friends of Ramsar Sites, Tema Metropolitan assembly and the Wildlife department to control indiscriminate release of effluents into the stream which drains into the Sakumono lagoon.

- Further studies should be carried out to establish the pollution load, trends and impact on the flora and fauna of the Onukpawahe stream and the Sakumono Lagoon (International Ramsar Site) in which the Onukpawahe stream drains. Wetlands greatly contribute to purification of wastewater and must be protected.
- Proper characterization of the industrial effluent and to investigate its impacts on stream ecology and quality.
- The Environmental Protection Agency (EPA) should enforce the pollution laws on effluent treatment facilities and efficient treatment on all the industries within the Onukpawahe stream catchment.
- The findings of this study would be useful for implementing pollution management strategies in the catchment area of the Onukpawahe Stream.

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APPENDICES

Appendix 1: Analytical Method 3005a

Acid Digestion of Waters for Total Recoverable or Dissolved Metals for Analysis by FLAA or ICP Spectroscopy

1.0 Scope and application

- Method 3005 is an acid digestion procedure used to prepare surface and ground water samples for analysis by flame atomic absorption spectroscopy (FLAA) or by inductively coupled argon plasma spectroscopy (ICP). Samples prepared by Method 3005 may be analyzed by AAS or ICP for the following metals: Aluminum, Magnesium, Antimony**, Manganese, Arsenic*, Molybdenum, Barium Nickel, Beryllium Potassium, Cadmium Selenium*, Calcium Silver, Chromium Sodium, Cobalt Thallium, Copper Vanadium, Iron Zinc and Lead* ICP only **May be analyzed by ICP, FLAA, or GFAA

When analyzing for total dissolved metals filter the sample, at the time of

collection, prior to acidification with nitric acid.

2.0 Summary of method

- Total recoverable metals - The entire sample was acidified at the time of collection with nitric acid. At the time of analysis the sample was heated with acid and substantially reduced in volume. The digestate was filtered and diluted to volume, and then ready for analysis.
- Dissolved metals - The sample is filtered through a 0.45- μm filter at the time of collection and the liquid phase is then acidified at the time of collection with nitric acid. Samples for dissolved metals do not need to be digested as long as the acid concentrations have been adjusted to the same concentration as in the standards.

3.0 Interferences

The analyst should be cautioned that this digestion procedure may not be sufficiently vigorous to destroy some metal complexes.

4.0 Apparatus and Materials

- Griffin beakers of assorted sizes or equivalent.
- Watch glasses or equivalent.
- Qualitative filter paper and filter funnels.
- Graduated cylinder or equivalent.
- Electric hot plate or equivalent - adjustable and capable of maintaining a temperature of 90-95 C.

5.0 Reagents

- Reagent grade chemicals were used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.
- Reagent Water. Reagent water was made interference free. All references to water in the method refer to reagent water unless otherwise specified
- Nitric acid (concentrated), HNO_3 . Acid was analyzed to determine level of impurities. If method blank is $< \text{MDL}$, then acid can be used.
- Hydrochloric acid (concentrated), HCl . Acid was analyzed to determine level of impurities. If method blank is $< \text{MDL}$, then acid can be used.

6.0 Sample Collection, Preservation, and Handling

- All samples were collected using EPA sampling method.
- All sample containers were prewashed with detergents, acids, and water. Both plastic and glass containers are suitable.

6.1 Sampling

- Total recoverable metals -All samples were acidified at the time of collection with HNO_3 (5mL/L).
- Dissolved metals - All samples were filtered through a 0.45- μm filter and then acidified at the time of collection with HNO_3 (5mL/L).

7.0 Procedure

- A 100-mL aliquot of well-mixed sample was transferred to a beaker.

- 2mL of concentrated HNO_3 and 5mL of concentrated HCl was added for the metals to be analysed. The sample was covered with a ribbed watch glass or other suitable covers and heated on hot plate at 90 to 95 C until the volume reduced to 15-20 mL.
- The beaker was removed and allowed to cool. The beaker was washed down walls and the watch glass with water and filtered or centrifuge the sample where necessary to remove silicates and other insoluble material that could clog the nebulizer. Filtration was done only where there was concern that insoluble materials may clog the nebulizer; this additional step is liable to cause sample contamination unless the filter and filtering apparatus are thoroughly cleaned and prerinsed with dilute HNO_3 .
- The final volume adjusted to 100mL with reagent water.

8.0 Quality Control

All quality control measures were followed. For each analytical batch of samples processed, blanks were carried throughout the entire sample preparation and analytical process. These blanks were useful in determining if samples were being contaminated. Replicate samples were processed on a routine basis. A replicate sample is a sample brought through the whole sample preparation and analytical process. Replicate samples were used to determine precision. The sample load will dictated the frequency, 5% was adapted.

Appendix 2: Water Quality Results (Effluent and Stream Samples)

Table 4.1A: Parameters measured in effluents from industries in the wet season

Parameters (Mean)	Sampling points					
NAME	Printex Limited	Healthilife Beverages	Coca cola Company Ltd	Kasapreko Company Ltd	Nutrifood Company Ltd	Accra Abattoir
pH	5.52±0.59	4.725±1.96	8.8±0.22	5.83±0.21	6.205±0.18	6.605±0.22
DO(mg/l)	6.05±0.64	7.29±0.35	7.11±1.32	4.77±0.17	9.265±1.00	4.675±0.16
TDS(ppm)	254.5±45.96	1239±354.97	895±982.9	409±72.12	292.5±120.92	2700±424.2
EC(µScm-1)	649±439.82	1946.5±641.35	1470±1371.79	681.5±139.30	458.5±161.93	5425±247.49
Turbidity(NTU)	59.15±11.10	72.6±23.19	4.01±0.83	520±0.00	212.05±236.10	136±11.31
Colour(TCU)	465±176.78	351.5±178.90	112.5±17.68	308.5±200.11	95±77.78	446.5±327.39
TSS(mg/l)	170±28.28	545±483.16	205±15.56	107±39.60	186.5±181.73	509±48.25
BOD(mg/l)	166±20	550.13±183	228.5±104	6906.6±873	353.5±7	9624±1085
COD(mg/l)	249.5±9	1543.5±108.19	217.5±201.53	10360±1852.62	675±49.49	14436±2300.95
Nitrite(mg/l)	0.127±0.02	0.001±0.00	0.2345±0.03	0.315±0.21	0.113±0.05	1.0655±1.46
Nitrate(mg/l)	6.3±0.68	30.9±5.66	4.393±2.88	0.2225±0.10	16.485±2.91	12.9±2.69
Sulphate(mg/l)	50.5±7.78	54.5±14.85	9.4±5.09	0.525±0.18	3.405±4.66	6.5±0.71
Phosphate(mg/l)	0.795±0.36	1.95±0.49	0.285±0.21	1.975±0.88	20.42±11.43	24.6±9.33
Ammonia(mg/l)	5.065±7.12	0.335±0.02	0.275±0.22	4.34±1.33	1.195±1.53	3.045±4.18
Zinc(mg/l)	0.03±0.03	0.3535±0.35	0.15±0.15	0.0055±0.01	0.001±0.00	0.04±0.04
Lead(mg/l)	0.553±0.55	0.012±0.01	0.002±0.00	0.0755±0.08	0.055±0.06	0.0195±0.02
Cadmium(mg/l)	0.1385±0.14	0.001±0.00	0.011±0.01	0.051±0.05	0.177±0.18	0.0285±0.03
Chromium(mg/l)	0.55±0.71	4.6605±3.92	0.01±0.00	7.205±0.63	0.405±0.07	3.45±1.48
Copper(mg/l)	0.59±0.35	0.0675±0.09	0.01±0.00	0.1055±0.15	0.83±1.02	5.894±1.92
T. Iron(mg/l)	0.175±0.18	0.2865±0.29	0.12±0.12	0.001±0.00	0.5±0.5	0.875±0.88

Table Parameters measured

4.1B: in effluents from industries in the dry season

Parameters (Mean)	Sampling points					
NAME	Printex Limited	Healthilife Beverages	Coca cola Company Ltd	Kasapreko Company Ltd	Nutrifood Company Ltd	Accra Abattoir
pH	6.36±0.25	5.43±0.22	9.20±0.66	6.24±0.78	5.71±1.55	7.45±0.42
DO(mg/l)	5.32±0.64	6.3±0.65	6.73±0.51	5.02±0.00	7.67±1.12	3.89±0.21
TDS(ppm)	1186±1441.65	325±67.83	1609±209.28	438±99.28	712±122.4	3288±1395.56
EC(μScm-1)	1833±27.02	489±105.46	2623±596.2	623±30.55	1084±245.08	5313±2201.83
Turbidity(NTU)	111±97.97	201±193.91	13±9.56	420±45.0	95±20.81	275±133.43
Colour(TCU)	685±247.6	433±29.18	149±78.75	415±92.60	557±66.38	1310±311.9
TSS(mg/l)	270±2.52	357±96.26	92±34.24	452±93.53	367±47.09	490±204.21
BOD(mg/l)	175±106.8	651±226.13	252±306.08	7759±616.53	734±751.79	14838±406.95
COD(mg/l)	323±265.7	1072±193.5	467±612	11638±924.7	1197±1044.8	22257±3713
Nitrite(mg/l)	0.107±0.07	0.001±0.00	0.21±0.04	0.70±0.30	0.11±0.03	1.08±0.9
Nitrate(mg/l)	7.93±10.68	1.87±1.15	3.57±3.31	3.81±3.06	0.86±1.29	10.29±15.40
Sulphate(mg/l)	68±13.75	60±29.37	25.6±2.97	0.74±0.17	9.33±1.53	8.17±1.89
Phosphate(mg/l)	0.76±0.66	2.460.84±	0.55±0.6	4.94±2.22	54.9±34.60	90.83±59.04
Ammonia(mg/l)	5.77±9.30	0.76±0.76	0.53±0.45	5.29±1.00	0.87±1.28	3.64±3.18
Zinc(mg/l)	0.06±0.03	0.26±0.23	0.29±0.33	0.01±0.01	0.004±0.01	0.58±0.93
Lead(mg/l)	0.52±0.24	0.02±0.00	0.02±0.00	0.014±0.01	0.08±0.01	0.02±0.01
Cadmium(mg/l)	0.12±0.04	0.001±0.00	0.01±0.00	0.001±0.00	0.17±0.04	0.03±0.01
Chromium(mg/l)	1.61±1.35	4.71±4.15	0.05±0.06	5.59±10.21	0.30±0.19	2.60±1.54
Copper(mg/l)	0.54±0.33	0.12±0.56	0.2±0.01	0.13±0.12	1.55±0.27	5.01±4.23

Table Parameters measured at selected

T. Iron(mg/l)	0.6±0.78	1.58±0.59	1.34±0.18	0.01±0.01	0.36±0.21	2.90±1.43
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4.1C: points on the stream during the wet season

Parameters (Means±SD)	Sampling Points															
	ST1	ST2	ST3	ST4	ST12	ST13	ST6	ST7	ST8	ST9	ST10	ST11	ST14	ST15	ST16	ST5
Ph	10.05±2.02	5.35±0.00	5.435±0.30	7.315±1.00	6.52±0.00	8.985±1.44	7.38±0.82	7.34±0.31	7.505±0.81	7.125±1.45	7.68±0.79	7.575±1.05	6.265±0.08	6.965±0.11	7.15±0.24	7.26±0.98
DO(mg/l)	1.68±0.5	6.27±1.41	8.5±2.47	7.13±4.93	7.95±0.02	6.44±3.78	5.6±3.44	6.5±0.97	5.6±1.77	7.5±0.21	7.48±1.15	6.9±1.01	6.52±0.11	7.04±0.62	6.61±0.20	7.205±0.84
TDS(ppm)	1005±473.7	1890±0.00	1571±889.54	1440±1041.49	2400±0.00	2017±1248.75	2503±1692.81	1262±146.95	2413.5±1819.39	2065±898.03	2256.5±1617.15	1513±688.72	173±179.61	258.61±	300±	1017±
EC(µScm-1)	1552.5±760.14	2820±0.00	2925±2114.25	2310±2177.89	5410±0.00	4029±822.39	1394.5±822.37	26728.5±2335.57	4934.5±4561.55	4145±2793	4662.5±4182.54	2978.5±2010.30	397.5±436.28	435.5±444.77	625±176.78	2045±1308.15
Turbidity(NTU)	63.6±10.47	78±0.00	124.5±70	38.1±28.43	36.1±5.8	252±210.72	137.2±46.95	339.5±44.55	73.5±21.92	47.2±1.13	10.85±1.2	30.25±21.57	54.1±0.00	35±21.21	65.5±13.44	59
Colour(TCU)	280±14.14	127±9.90	223.5±174.66	296.5±386.79	252.5±17.68	147±59.40	67.5±49.96	230±70.71	32.5±3.54	91±26.49	52.5±17.68	117.5±31.82	237.5±45.96	45±15.56	90.5±21.92	100±113.4
TSS(mg/l)	149.5±119.5	127±49.50	223.5±14.85	151±55.15	145±70.71	85±12.73	43.5±3.54	110.5±20.01	47.54±55.80	143±82.02	121±5.66	102±91.92	96±12.73	77.5±57.28	135±14.14	86.5±84.15
BOD(mg/l)	411±122	162±36	149±2	109±11	83.5±4	117.5±10	230±74	101.5±4	78±11	65.5±7	60.5±7	121.5±4	48.5±7	85.5±13	76.5±2	68.5±1.0
COD(mg/l)	553.5±348.6	249±7.07	223.5±4.95	153.5±51.62	132.5±3.52	315±70.71	320±144.4	217.5±3.54	115±21.21	80±7.10	91.5±2.12	252±67.88	83±21.11	104.5±3.54	114±2.82	109±15.56
Nitrite(mg/l)	0.025±0.01	0.34±0.03	0.1345±0.03	0.101±0.14	0.092±0.00	0.115±0.01	0.066±0.09	0.1105±0.15	0.374±0.42	0.0535±0.05	0.11±0.01	0.13±0.01	0.02±0.01	0.92±0.04	0.0215±0.00	0.07±0.09
Nitrate(mg/l)	0.025±0.00	0.34±0.00	0.1345±0.65	0.101±0.03	0.092±1.41	0.115±0.62	0.066±1.86	0.1105±0.50	0.374±0.00	0.0535±0.54	0.1055±0.27	0.128±1.15	0.02±0.09	0.92±1.12	0.0215±0.21	0.0715±0.86
Sulphate(mg/l)	5.18±2.29	4.33±5.19	0.01±0.00	21.5±23.33	1.05±0.04	0.02±0.01	1.585±2.00	7.555±10.53	1.0005±1.41	9.005±1.42	0.03±0.01	17.01±24.03	1.505±2.11	3±1.41	8.265±1.83	39.5±4.95
Phosphate(mg/l)	28.5±7.78	83±0.00	40±22.63	19.5±2.12	17.5±	55±1.41	30.265±33.28	61.5±25.17	2.5±0.71	65.1±28.99	39.9±0.00	42.4±14.71	21.9±1.56	20±2.28	23.54±0.34	19.64±26.81

Table Parameters measured

Ammonia(mg/l)	16±5.66	0.66±0.00	0.02±0.01	0.32±0.23	0.08±0.00	0.04±0.01	0.14±0.04	0.1005±0.01	0.1155±0.16	0.4905±0.69	0.085±0.06	0.26±0.34	0.02±0.01	2.725±3.32	0.17±0.06	0.0055±0.01
Zinc(mg/l)	0.001±0.00	0.035±0.04	0.001±0.00	0.001±0.00	0.04±0.01	1.4±0.28	0.03±0.00	0.001±0.00	0.001±0.00	0.01±0.00	0.001±0.01	0.01±0.00	0.01±0.00	0.01±0.00	0.0115±0.00	0.0205±0.03
Lead(mg/l)	0.307±0.13	0.0065±0.01	0.12725±0.01	0.01±0.01	0.01±0.00	0.016±0.01	0.001±0.00	0.001±0.00	0.0055±0.01	0.0059±0.01	0.0055±0.01	0.01±0.00	0.069±0.10	0.001±0.00	0.001±0.00	0.026±0.02
Cadmium(mg/l)	0.1152±	0.0015±	0.0605±0.00	0.01511±0.00	0.0155±0.00	0.0015±0.00	0.01665±0.00	0.022±0.00	0.012035±0.00	0.083±0.01	0.01545±0.00	0.0185±0.00	0.1505±0.04	0.0925±0.06	0.001±0.06	0.026±0.00
Chromium(mg/l)	0.001±0.00	0.02±0.01	0.006±0.01	0.106±0.07	0.001±0.00	0.0705±0.10	0.02±0.1	0.011±0.02	0.075±0.00	0.03±0.02	0.02±0.01	0.02±0.00	0.01±0.00	0.001±0.01	0.001±0.00	0.0105±0.01
Copper(mg/l)	0.31±0.07	0.9955±0.02	0.11±0.01	0.001±0.00	0.8025±1.18	0.586±0.06	0.39±0.10	1.1105±1.54	0.2855±0.38	0.1605±0.11	0.12±0.15	0.08±0.10	0.625±0.87	0.006±0.01	0.001±0.001	0.05±0.02
T. Iron(mg/l)	0.17±0.01	0.15±0.00	0.14±0.02	0.20±0.28	0.16±02.4	1.755±0.02.47	1.45±1.91	0.225±0.25	0.05±0.07	0.24±0.08	0.03±0.02	0.05±0.00	0.13±0.03	0.835±0.08	0.226±0.07	0.13±0.17



Table Parameters measured at selected points in the stream during the dry season

4.1D:

Parameters (Mean±SD)	Sampling Points															
	ST1	ST2	ST3	ST4	ST12	ST13	ST6	ST7	ST8	ST9	ST10	ST11	ST14	ST15	ST16	ST5
pH	8.36±2.24	7.65±0.23	6.63±0.49	7.73±1.39	7.1±0.92	8.06±0.33	7.71±0.2	7.60±0.36	7.87±0.10.36	7.72±0.0.13	7.73±0.0.15	7.73±0.00.30	7.173±0.08	7.03±0.06	7.33±0.12	7.65±0.19
DO(mg/l)	5.88±1.3	4.8±1.74	5.70±1.14	6.90±0.47	7.12±0.87	5.62±1.28	4.77±1.10	6.59±0.36	7.39±0.96	7.73±1.12	7.89±0.20	7.78±0.0.91	7.87±1.16	7.23±0.40	7.03±0.42	7.55±0.75
TDS(ppm)	405±44	1063±488.42	461±27.00	1026±423.7	655±337.8	936±515.5	1275±283.73	852±665	1080±725	983±786	1119±901.9	931±709.09	71±22.17	333±230	310±32.72	1785±269.4
EC(µScm-1)	651±11.36	1673±675.01	744±75.59	1609±557.23	601±234.13	1478±730.35	2044±352	1330±951	1680±1077	1507±115.96	1709±1356.17	1422±1056	112.9±28.63	529±352	625±67.64	2737±4068.13
Turbidity(NTU)	43±17.44	39.4±13.82	53±12.18	116±105.63	57±22.16	101±129.57	78±18.54	84.1±5.15	16±1.13	31.3±5.71	9.37±0.82	24±7.13	91.2±42.31	88±27.97	39±5.29	203±208.96
Colour(TCU)	453±125.31	305±82.61	519±78.75	783±160.03	497±274	157±44.99	168±24.21	287±85	94±13.89	166±41.33	89±17.79	147±16.8	128±12.58	66±11.24	119±5.29	175±36.6
TSS(mg/l)	225±57.19	198±7.51	241±28.21	788±32.19	180±61.54	296±150.19	182±15.18	628±23.46	194±35.64	215±39.36	194±4.04	203±15.31	117±2.08	125±6.24	151±29.28	179±68.82
BOD(mg/l)	677±248.49	284±81.46	408±152.7	362±97.17	396±260.9	345±279.29	357±160.08	423±58.97	155±50.88	238±139.89	120±46.83	245±101.72	90±4.2	118±34.87	79±14.68	159±68.55
COD(mg/l)	977±439.8	465±60.04	613±229.	408±100.8	442±60.4	526±113.69	750±160.92	683±15.22	247±51.32	390±153.95	207±37.8	417±68.09	135±6.11	190±29.8	119±22.03	270±70
Nitrite(mg/l)	0.01±0.01	0.53±0.09	0.12±0.01	0.11±0.08	0.14±0.04	0.18±0.007	0.26±0.11	0.10±0.10	0.298±0.36	0.11±0.02	0.12±0.14	0.30±0.04	0.06±0.03	1.02±0.00	0.06±0.06	0.21±0.06
Nitrate(mg/l)	1.35±1.99	1.95±3.02	1.70±2.62	0.38±0.03	4.87±3.91	7.45±1.26	1.76±2.73	1.01±0.90	0.39±0.39	0.38±0.48	1.27±0.60	1.62±1.38	0.23±0.18	0.54±0.48	0.36±0.07	2.7±4.04
Sulphate(mg/l)	11.83±4.54	26.33±28.73	6.43±5.52	65.67±42.83	45.67±31.77	108±19.31	42±15.01	43.33±27.61	35.33±2.08	53.67±6.00	48±12.53	26±2.50	5.53±1.62	5.87±4.93	17.50±	28.67±17.21
Phosphate(mg/l)	31.8±30.05	69.37±13.09	25.6±13.83	66.6±16.99	57.29±29.43	99.7±10.06	58.33±59.93	55.83±27.01	17.93±48.36	50.43±19.66	50.57±20.92	66.9±18.75	31.9±15.41	31.67±5.81	26.83±0.46	46.43±3.99
Ammonia(mg/l)	0.20±0.33	0.15±0.10	0.74±1.09	0.44±0.51	0.08±0.02	0.04±0.06	0.91±0.06	0.17±0.19	0.55±0.22	0.46±0.44	0.34±0.27	0.79±0.16	0.23±0.36	0.84±0.08	0.39±0.05	0.007±0.01
Zinc(mg/l)	0.29±0.33	0.21±0.16	0.35±0.37	0.55±0.48	0.79±0.64	1.09±0.88	0.34±0.27	0.11±0.09	0.09±0.08	0.08±0.0	0.034±0.06	0.074±0.06	0.007±0.01	0.012±0.00	0.014±0.00	0.22±0.37
Lead(mg/l)	0.33±0.12	0.012±0.00	0.14±0.00	0.005±0.01	0.012±0.00	0.022±0.00	0.002±0.00	0.001±0.00	0.004±0.00	0.014±0.00	0.014±0.00	0.017±0.01	0.10±0.09	0.05±0.08	0.001±0.00	0.07±0.01
Cadmium(mg/l)	0.19±0.07	0.008±0.01	0.08±0.01	0.09±0.11	0.21±0.17	0.01±0.00	0.13±0.19	0.034±0.01	0.12±0.09	0.11±0.09	0.05±0.05	0.27±0.24	0.09±0.08	0.32±0.38	0.001±0.00	0.03±0.01
Chromium(mg/l)	0.03±0.04	0.10±0.04	0.08±0.07	0.13±0.05	0.03±0.03	0.02±0.03	0.06±0.05	0.041±0.04	0.073±0.05	0.07±0.04	0.044±0.06	0.04±0.03	0.001±0.00	0.11±0.09	0.001±0.00	0.06±0.03
Copper(mg/l)	0.23±0.08	1.17±0.06	0.12±0.01	0.10±0.00	1.54±0.48	1.31±0.00	0.53±0.48	2.14±0.36	0.55±0.07	0.86±0.12	0.303±0.02	0.23±0.03	0.88±0.75	0.01±0.0	0.011±0.00	0.07±0.02
T. Iron(mg/l)	0.147±0.12	0.45±0.28	2±1.68	0.17±0.10	0.6±0.74	4.77±3.5	0.52±0.48	0.55±0.28	0.17±0.08	0.28±0.32	0.18±0.08	0.18±0.10	0.29±0.27	1.31±0.10	0.31±0.03	0.48±0.38

Table Parameters measured at selected

4.1E: industries for the entire five months period

Parameters (Mean)	Sampling points						
	Printex Limited	Healthlife Beverages	Coca cola Company Ltd	Kasapreko Company Ltd	Nutrifood Company Ltd	Accra Abattoir	EPA Value
pH	5.94	5.08	9.00	6.03	5.96	7.03	6 – 9
DO(mg/l)	6.43	5.74	6.14	7.09	6.12	6.59	5
TDS(ppm)	720	782	1252	424	502	2994	1000
EC(μScm-1)	1241	1218	2047	652	771	5369	1500
Turbidity(NTU)	85	137	8	470	154	206	75
Colour(TCU)	575	392	131	362	326	878	200
TSS(mg/l)	220	451	149	280	277	500	50
BOD(mg/l)	170	601	240	7333	544	12231	50
COD(mg/l)	286	1308	342	10999	936	18346	250
Nitrite(mg/l)	0.117	0.001	0.224	0.509	0.112	1.071	-
Nitrate(mg/l)	7.116	16.383	3.981	2.018	8.671	11.595	50
Sulphate(mg/l)	59.250	57.417	17.500	0.631	6.369	7.333	200
Phosphate(mg/l)	0.778	2.207	0.419	3.459	37.660	57.717	2

Table Parameters measured at selected

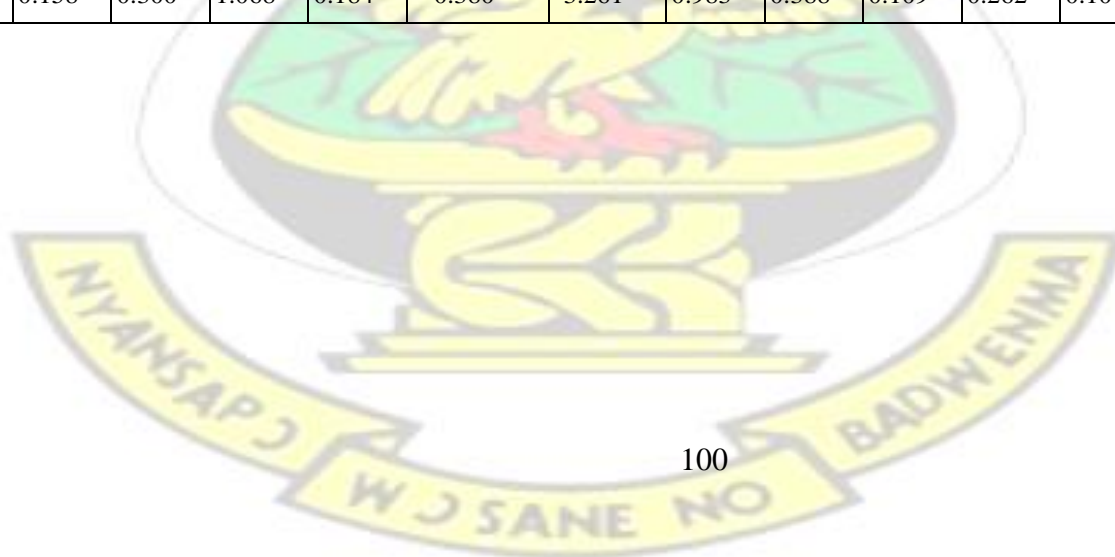
Ammonia(mg/l)	5.416	0.546	0.402	4.817	1.031	3.341	1
Zinc(mg/l)	0.046	0.307	0.218	0.007	0.003	0.311	10
Lead(mg/l)	0.538	0.016	0.010	0.045	0.069	0.018	0.1
Cadmium(mg/l)	0.128	0.001	0.011	0.026	0.172	0.028	0.1
Chromium(mg/l)	1.080	4.687	0.029	6.398	0.355	3.027	0.5
Copper(mg/l)	0.566	0.092	0.105	0.120	1.191	5.450	5.0
T. Iron(mg/l)	0.388	0.934	0.732	0.005	0.430	1.886	10.0

4.1F:**points along the Onukpawahe Stream for the entire five months period**

Parameters (Mean)	Sampling Points															
	T1	T2	T3	T4	T12	T13	T6	T7	T8	T9	T10	T11	T14	T15	T16	T5
pH	9.20	6.50	6.03	7.52	6.81	8.52	7.55	7.47	7.69	7.42	7.71	7.65	6.72	7.00	7.24	7.46
DO(mg/l)	3.78	5.54	7.10	7.02	7.53	6.03	5.18	6.54	6.50	7.61	7.69	7.34	7.19	7.16	6.82	7.38
TDS(ppm)	705	1476	1016	1233	1527	1476	1889	1057	1747	1524	1688	1222	122	296	305	1401
EC(μ Scm-1)	1102	2247	1834	1960	3006	2753	1719	14029	3307	2826	3186	2200	255	482	625	2391
Turbidity(NTU)	53	59	89	77	46	176	107	212	45	39	10	27	73	61	52	123
Colour(TCU)	367	216	371	540	375	152	118	258	63	129	71	132	183	55	105	138
TSS(mg/l)	187	162	232	469	163	190	113	369	121	179	158	153	107	101	143	133

Table Parameters measured at selected

BOD(mg/l)	544	223	279	235	240	231	294	262	116	152	90	183	69	102	78	114
COD(mg/l)	765	357	418	281	287	420	535	450	181	235	149	334	109	147	116	190
Nitrite(mg/l)	0.017	0.437	0.127	0.107	0.117	0.150	0.161	0.107	0.336	0.080	0.115	0.215	0.039	0.970	0.041	0.138
Nitrate(mg/l)	1.316	1.808	1.089	0.349	5.233	6.096	2.626	0.719	0.198	0.401	0.810	2.318	0.237	0.672	0.263	1.963
Sulphate(mg/l)	8.507	15.332	3.222	43.583	23.358	54.010	21.793	25.444	18.167	31.336	24.015	21.505	3.519	4.433	12.881	34.083
Phosphate(mg/l)	30.150	76.183	32.800	43.050	37.393	77.350	44.299	58.667	10.217	57.767	45.233	54.650	26.900	25.833	25.187	33.037
Ammonia(mg/l)	8.099	0.407	0.382	0.382	0.079	0.038	0.526	0.135	0.334	0.477	0.213	0.527	0.125	1.782	0.282	0.006
Zinc(mg/l)	0.147	0.123	0.177	0.275	0.417	1.248	0.187	0.055	0.047	0.045	0.018	0.042	0.009	0.011	0.013	0.122
Lead(mg/l)	0.318	0.009	0.135	0.008	0.011	0.020	0.002	0.001	0.005	0.010	0.010	0.013	0.084	0.025	0.001	0.046
Cadmium(mg/l)	0.151	0.005	0.070	0.051	0.112	0.004	0.074	0.028	0.064	0.095	0.033	0.147	0.121	0.204	0.001	0.026
Chromium(mg/l)	0.017	0.042	0.043	0.117	0.017	0.045	0.036	0.026	0.074	0.048	0.032	0.030	0.003	0.053	0.001	0.034
Copper(mg/l)	0.268	1.080	0.113	0.052	1.171	0.946	0.462	1.627	0.418	0.510	0.209	0.155	0.751	0.008	0.006	0.057
T. Iron(mg/l)	0.158	0.300	1.068	0.184	0.380	3.261	0.983	0.388	0.109	0.262	0.107	0.117	0.212	1.072	0.270	0.307



Table

4.1G: Mean concentration of Total and Faecal coliform in the stream

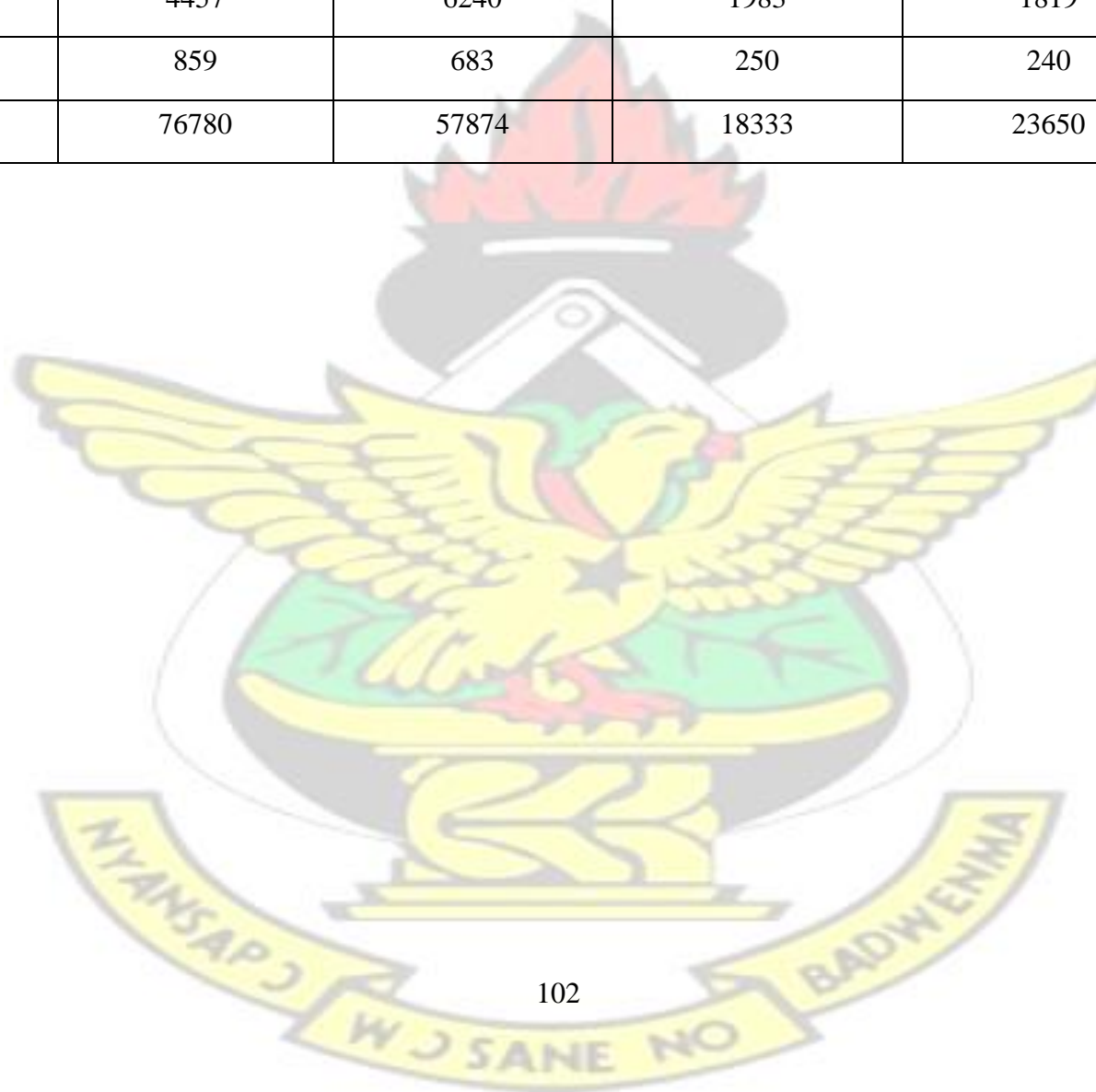
Coliform(MPN/100ml)					
Mean	Dry/Total Coliform	Wet/Total Coliform	Dry/Faecal Coliform	Wet/Faecal Coliform	EPA
ST1	1423	1562	361	652	400
ST2	9000	10528	7756	9670	400
ST3	1943	3465	1406	2096	400
ST4	1024	1365	866	739	400
ST12	2218	3316	1053	1193	400
ST13	5580	6934	1064	1682	400
ST6	12989	14000	1034	4095	400
ST7	5805	8215	748	815	400
ST8	4100	4930	2321	3679	400
ST9	6060	9902	5902	8266	400
ST10	7104	9908	3480	5062	400
ST11	2562	3827	522	676	400
ST14	299	396	220	323	400
ST15	871	1066	326	520	400
ST16	391	486	178	338	400
ST5	644	890	442	474	400

Table 4.1H: Mean concentration of Total and Faecal coliform in the industrial effluent

Coliform(MPN/100ml)					
Mean concentration	Dry/Total Coliform	Wet/Total Coliform	Dry/Faecal Coliform	Wet/Faecal Coliform	EPA
Printex	538	850	173	270	400
Healthilife	534	300	25	20	400

Table

Coca cola	8	59	3	5	400
Kasapreko	4457	6240	1983	1819	400
Nutrifood	859	683	250	240	400
Accra Abattoir	76780	57874	18333	23650	400



Appendix 3: ANOVA Analysis

Table 4.A. ANOVA for comparing the wet and dry period

WET and DRY	STREAM
ANOVA(BETWEEN SITES)	P-value
pH	0.298
DO(mg/l)	0.522
TDS(ppm)	0.005
EC(μ Scm-1)	0.001
Turbidity(NTU)	0.382
Colour(TCU)	0.056
TSS(mg/l)	0.005
BOD(mg/l)	0.002
COD(mg/l)	0.002
Nitrate(mg/l)	0.722
Sulphate(mg/l)	0.006
Phosphate(mg/l)	0.081
Ammonia(mg/l)	0.357
Zinc(mg/l)	0.067
Lead(mg/l)	0.69
Cadmium(mg/l)	0.016
Chromium(mg/l)	0.021
Copper(mg/l)	0.142
T. Iron(mg/l)	0.216

Table 4B ANOVA for Upstream and Down Stream after discharge points

ANOVA		Sum of Squares	df	Mean Square	F	P-Value.
BOD	Between Groups	616025.437	2	308012.719	7.515	.008
	Within Groups	491808.089	12	40984.007		
	Total	1107833.526	14			
COD	Between Groups	1261536.933	2	630768.467	8.944	.004
	Within Groups	846310.000	12	70525.833		
	Total	2107846.933	14			
TDS	Between Groups	2852820.133	2	1426410.067	3.763	.049
	Within Groups	4549129.600	12	379094.133		
	Total	7401949.733	14			
CONDUCTIVITY	Between Groups	10078514.533	2	5039257.267	2.053	.171
	Within Groups	29455128.400	12	2454594.033		
	Total	39533642.933	14			
TSS	Between Groups	6298.133	2	3149.067	.860	.448

	Within Groups	43941.600	12	3661.800		
	Total	50239.733	14			
DO	Between Groups	4.145	2	2.072	4.396	.037
	Within Groups	5.657	12	.471		
	Total	9.802	14			
Temperature	Between Groups	9.124	2	4.562	1.308	.306
	Within Groups	41.840	12	3.487		
	Total	50.964	14			
pH	Between Groups	13.320	2	6.660	3.632	.058
	Within Groups	22.002	12	1.834		
	Total	35.323	14			
Turbidity	Between Groups	16.657	2	8.329	.026	.974
	Within Groups	3847.800	12	320.650		
	Total	3864.457	14			
Colour	Between Groups	269430.933	2	134715.467	5.550	.020
	Within Groups	291278.000	12	24273.167		
	Total	560708.933	14			
Nitrite	Between Groups	.030	2	.015	11.013	.002
	Within Groups	.017	12	.001		
	Total	.047	14			
Nitrate	Between Groups	87.958	2	43.979	39.183	.000
	Within Groups	13.469	12	1.122		
	Total	101.427	14			
Ammonia	Between Groups	.143	2	.071	2.590	.116
	Within Groups	.331	12	.028		
	Total	.474	14			
Phosphate	Between Groups	912.877	2	456.439	1.588	.244
	Within Groups	3448.510	12	287.376		
	Total	4361.387	14			
T.Coliform	Between Groups	25469232.133	2	12734616.067	1.514	.259
	Within Groups	100947143.600	12	8412261.967		
	Total	126416375.733	14			
F.Coliform	Between Groups	2009299.733	2	1004649.867	48.733	.000
	Within Groups	247386.000	12	20615.500		
	Total	2256685.733	14			
T.Iron	Between Groups	.180	2	.090	.792	.475
	Within Groups	1.363	12	.114		
	Total	1.543	14			
Lead	Between Groups	.328	2	.164	42.849	.000
	Within Groups	.046	12	.004		
	Total	.374	14			
Zinc	Between Groups	.593	2	.297	1.943	.186
	Within Groups	1.832	12	.153		
	Total	2.425	14			
Cadmium	Between Groups	.071	2	.035	3.548	.062
	Within Groups	.120	12	.010		
	Total	.190	14			
T.Chromium	Between Groups	.001	2	.001	.924	.423
	Within Groups	.008	12	.001		
	Total	.009	14			

Copper	Between Groups	4.276	2	2.138	10.590	.002
	Within Groups	2.423	12	.202		
	Total	6.699	14			

Appendix 4: Water Quality Index Calculator and Ranking

Table 4.1A: Water Quality Index Calculator showing calculated value for site ST 3

Water Quality Index Calculator						
	TEST			Weighting	Weighting	
Parameter	RESULT	Units	Q-value	Factor	Factor	Subtotal
pH	6.15	pH units	62	0.12	0.12	7.49
Change in temp	0	degrees C	93	0.11	0.11	10.23
DO	65	% saturation	67	0.18	0.18	12.02
BOD	305	mg/L	2	0.12	0.12	0.24
Turbidity	81.56	NTU	24	0.09	0.09	2.20
Total Phosphate	31.36	mg/L	5	0.11	0.11	0.55
Nitrate Nitrogen	1.2	mg/L NO ₃ -N	68	0.10	0.10	6.82
TDS	560	ppm	20	0.07	0.07	4.12
Faecal Coliforms*	780	MPN/100 mL	24	0.17	0.17	4.05
*Only use one microorganism,				TOTALS:	1.07	47.72
not faecal coliforms AND E. coli		NM = Not Measured		Water Quality Index =		40.79
				Water Quality Rating =		POOR

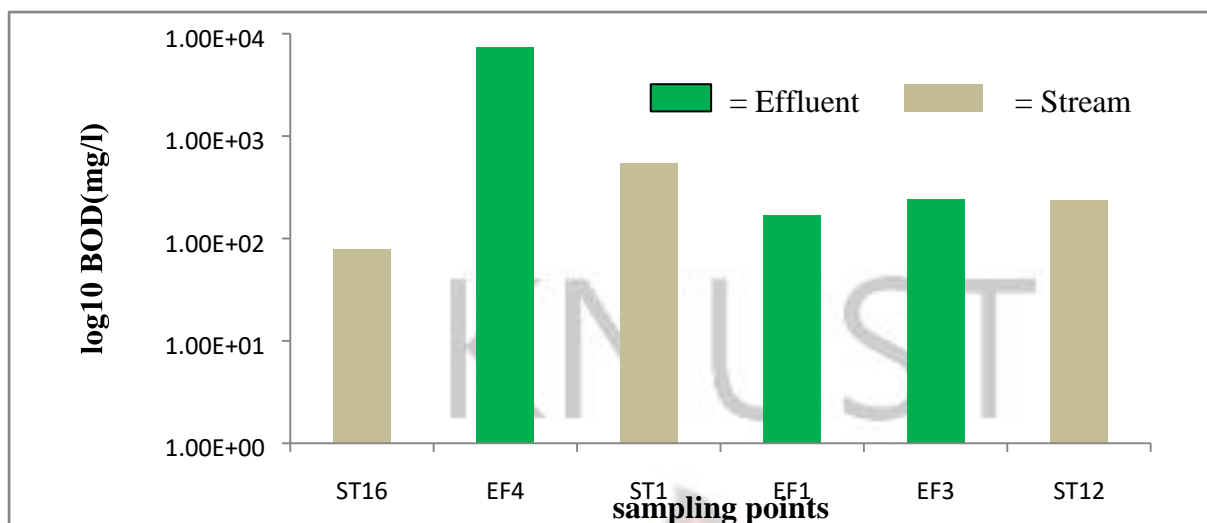
Table 4.2: Water Quality Index Legend

classification	Ranking(CCME WQI)	Meaning

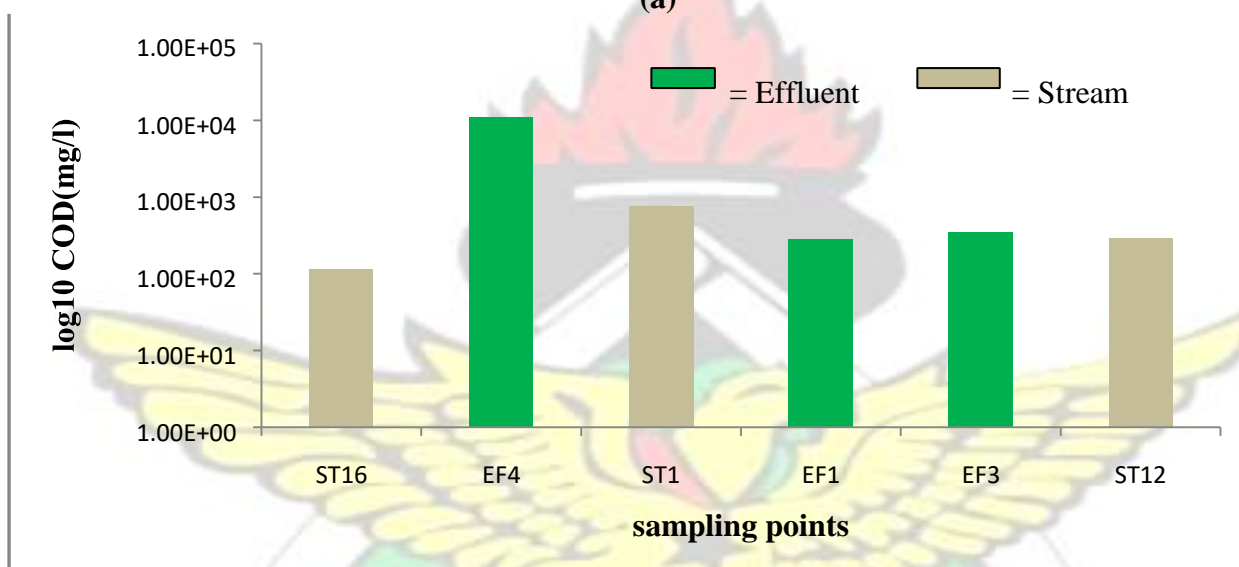
Excellent	95-100	Water quality is protected with no threat or impairment, condition very closed to natural
Good	80-94	Water quality is protected with only minor degree of threat or impairment; condition rarely departs from natural or desirable levels
Fair	65-79	Water quality is usually protected but occasionally threaten or impaired; conditions occasionally departs from natural or desirable levels
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often departs from natural or desirable levels
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

Source: (CCME 2001)

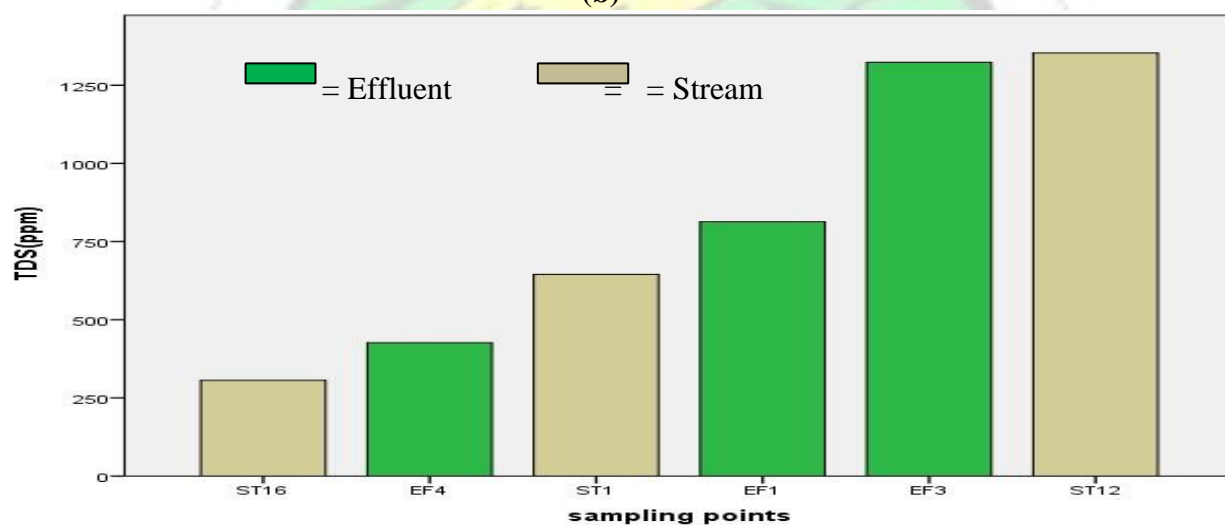
Appendix 5: Graph of Upstream and Downstream Compared after Discharge Point

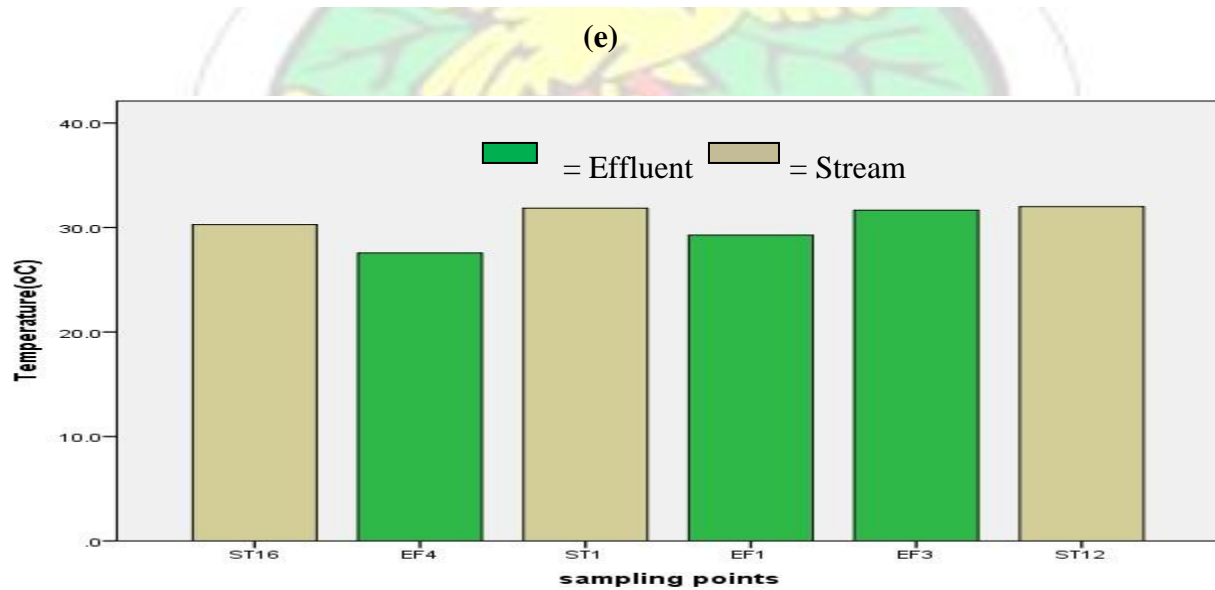
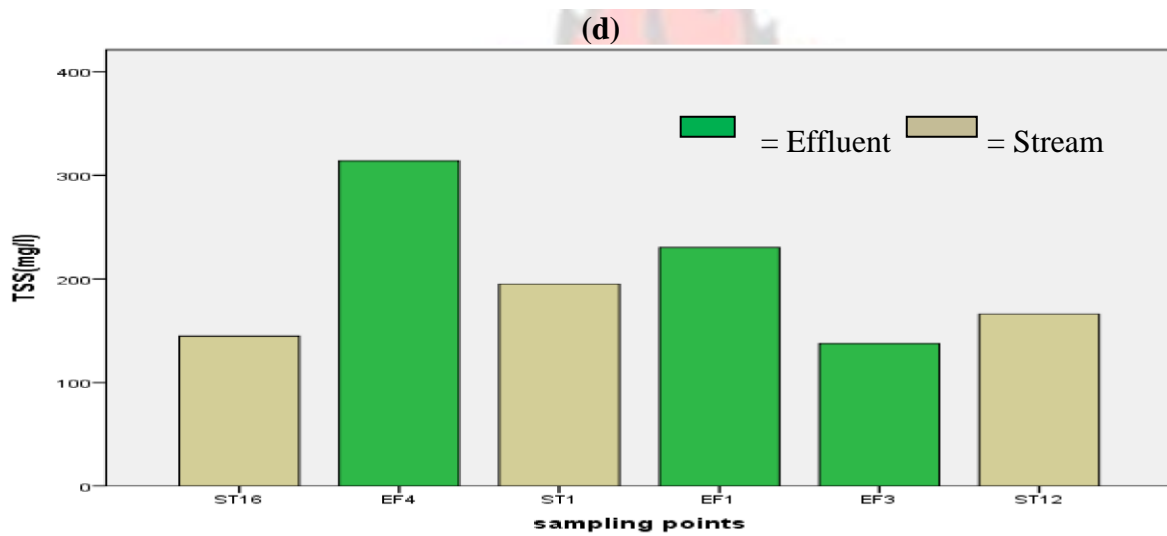
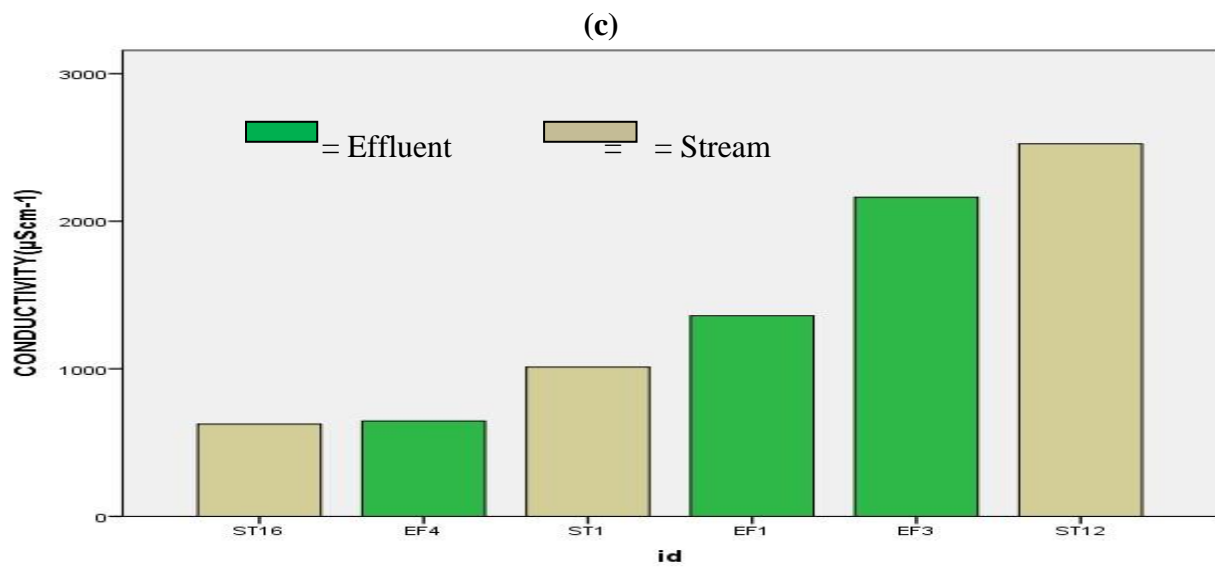


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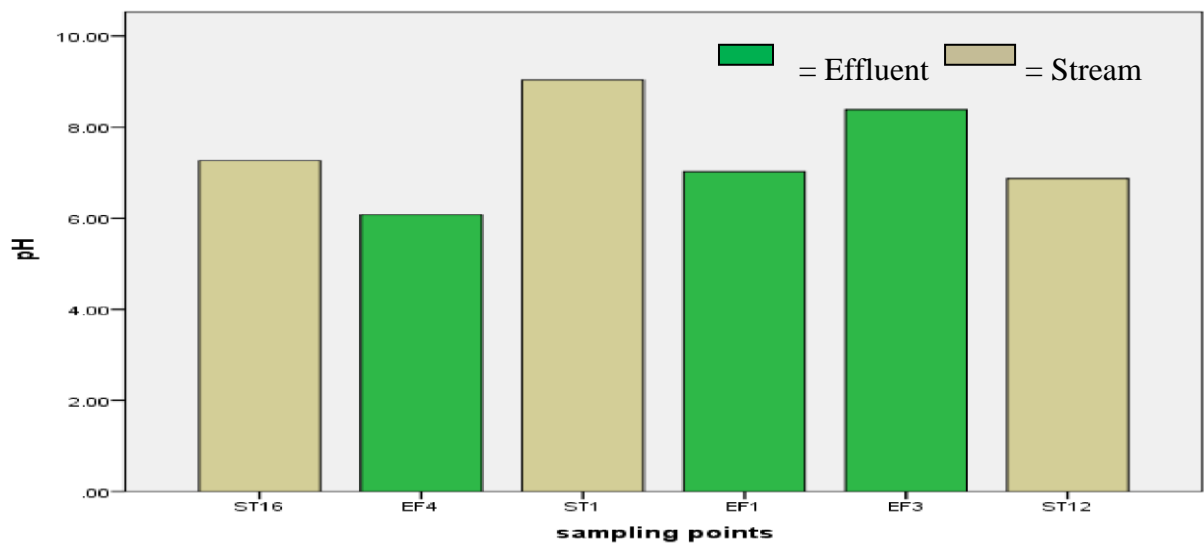


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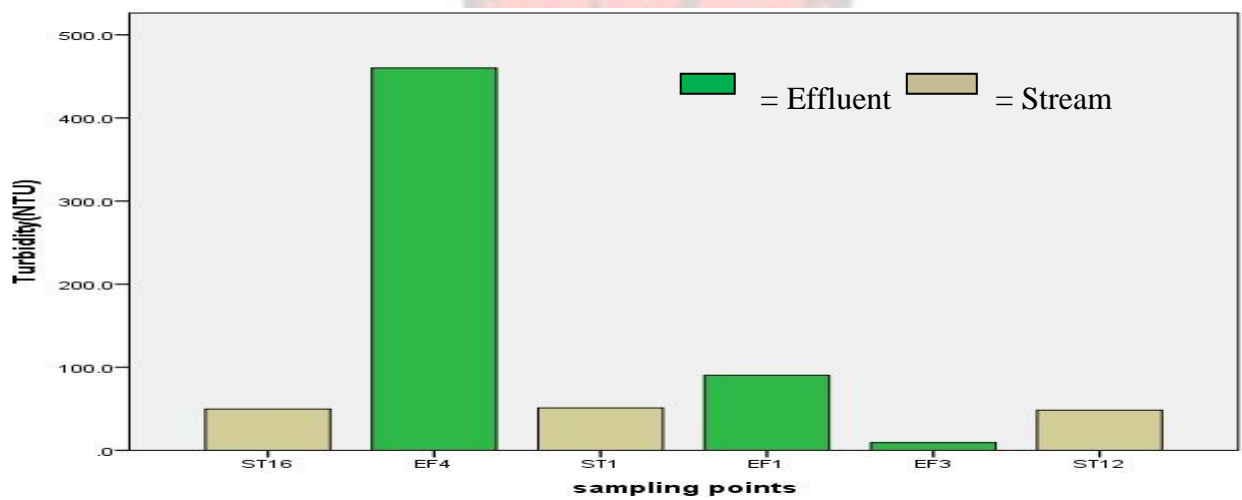




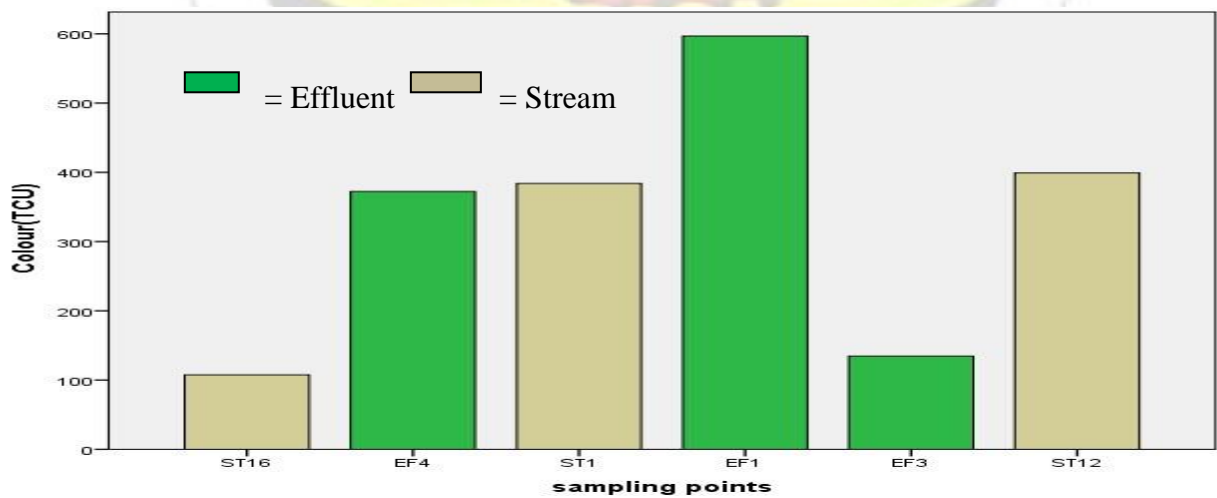
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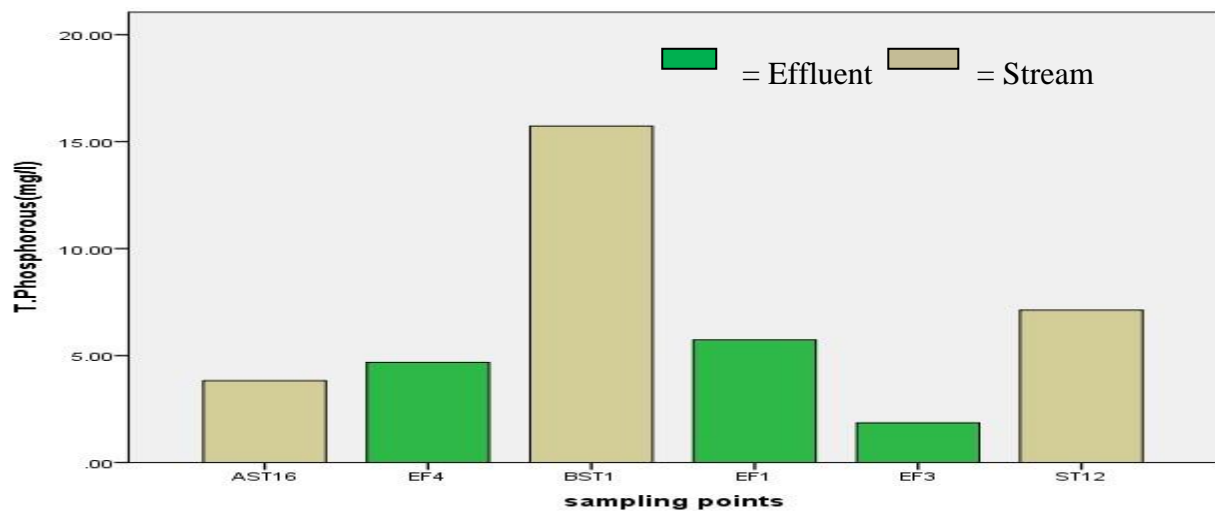
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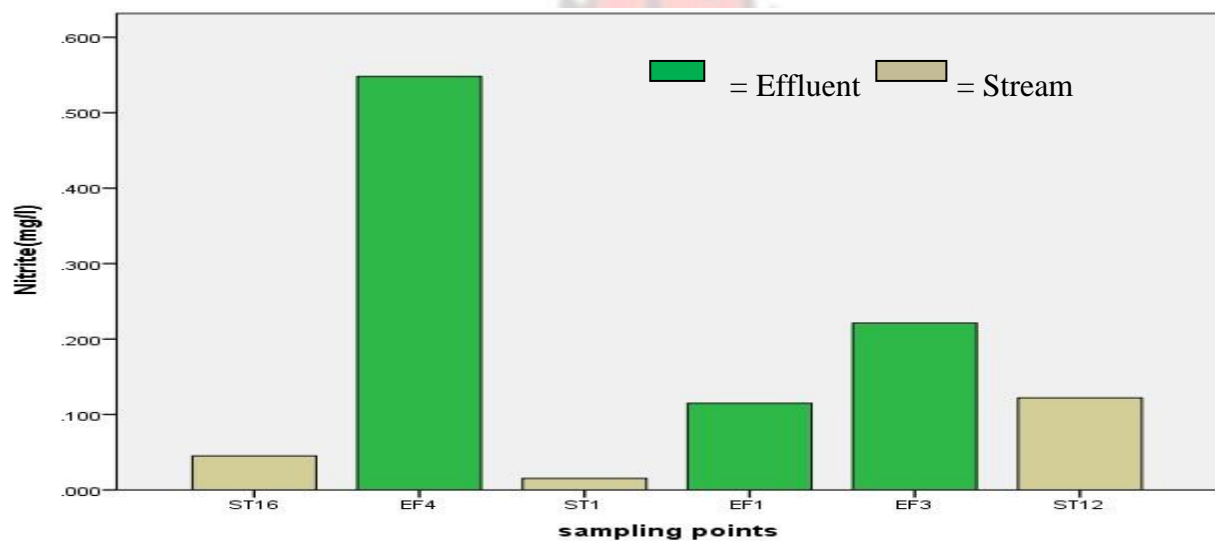
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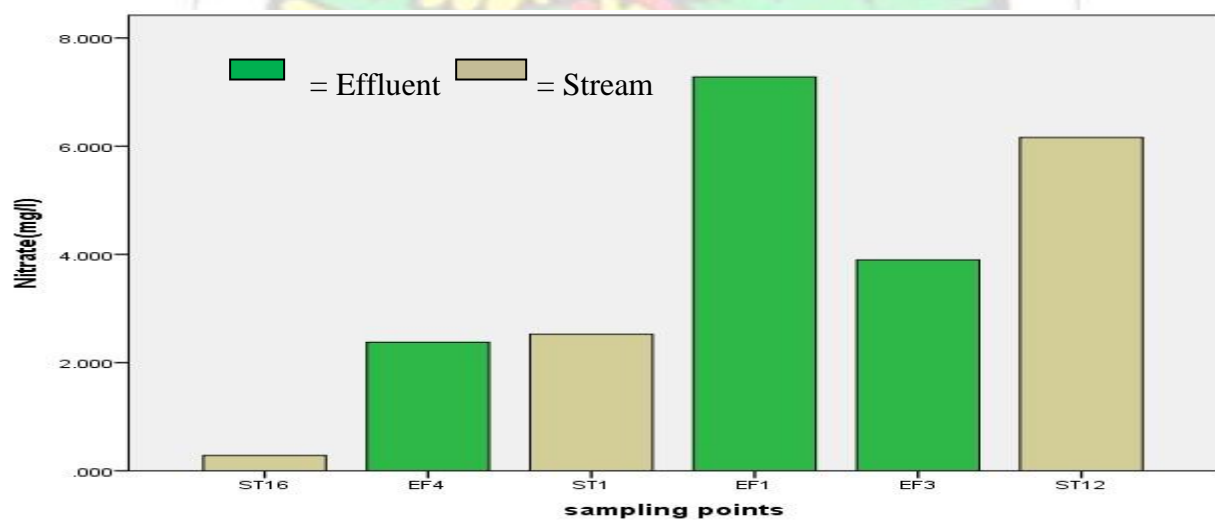
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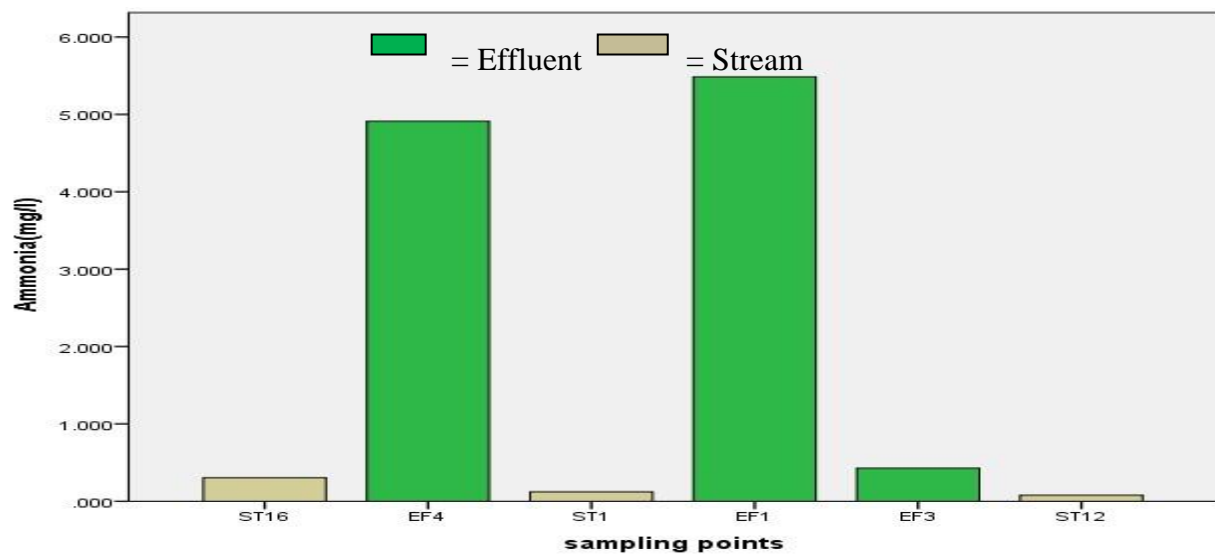
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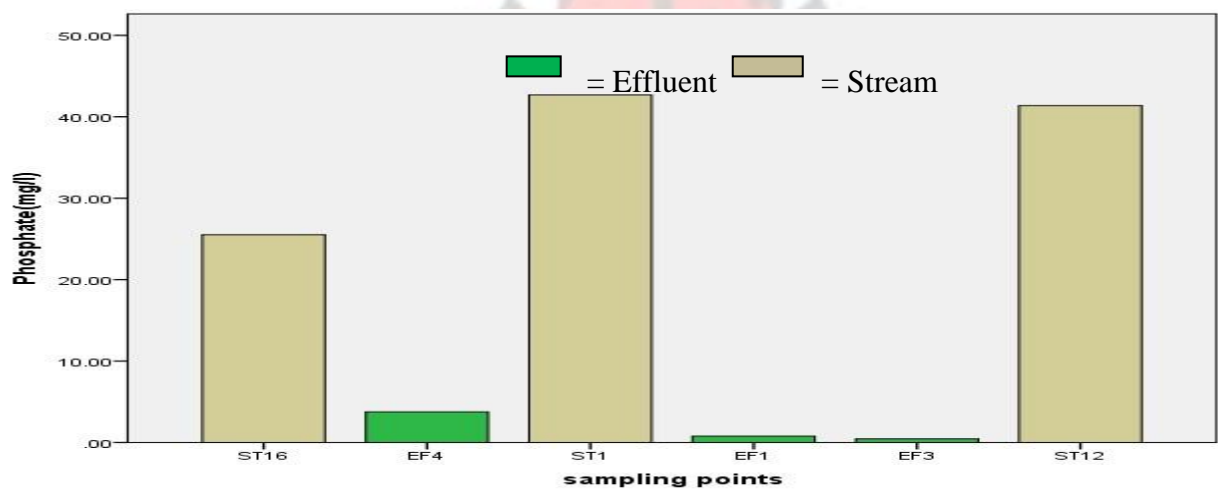
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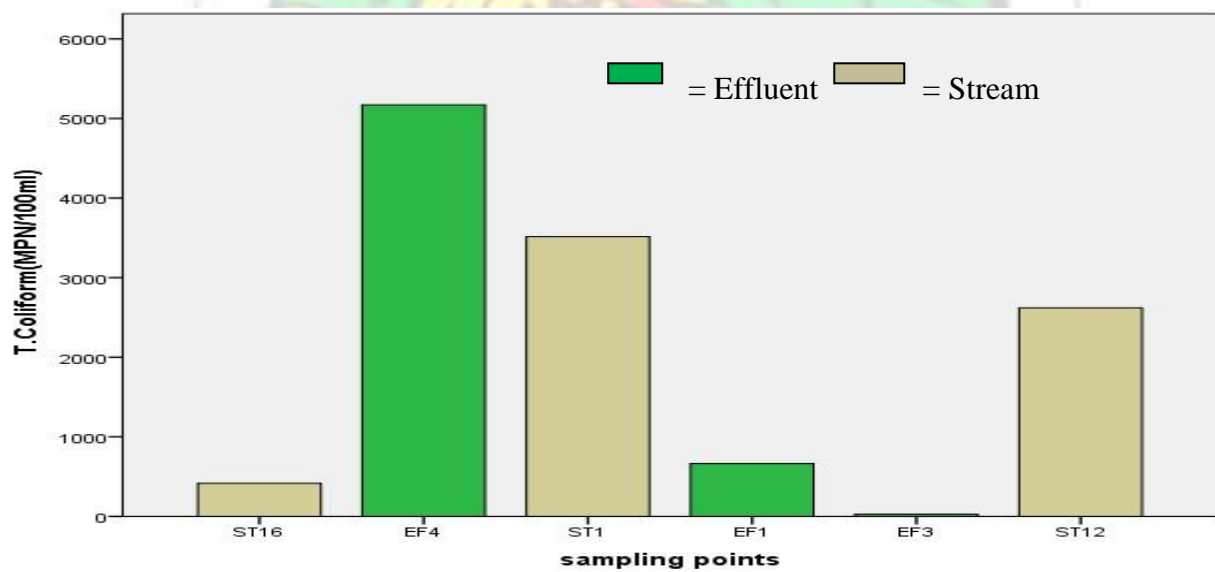
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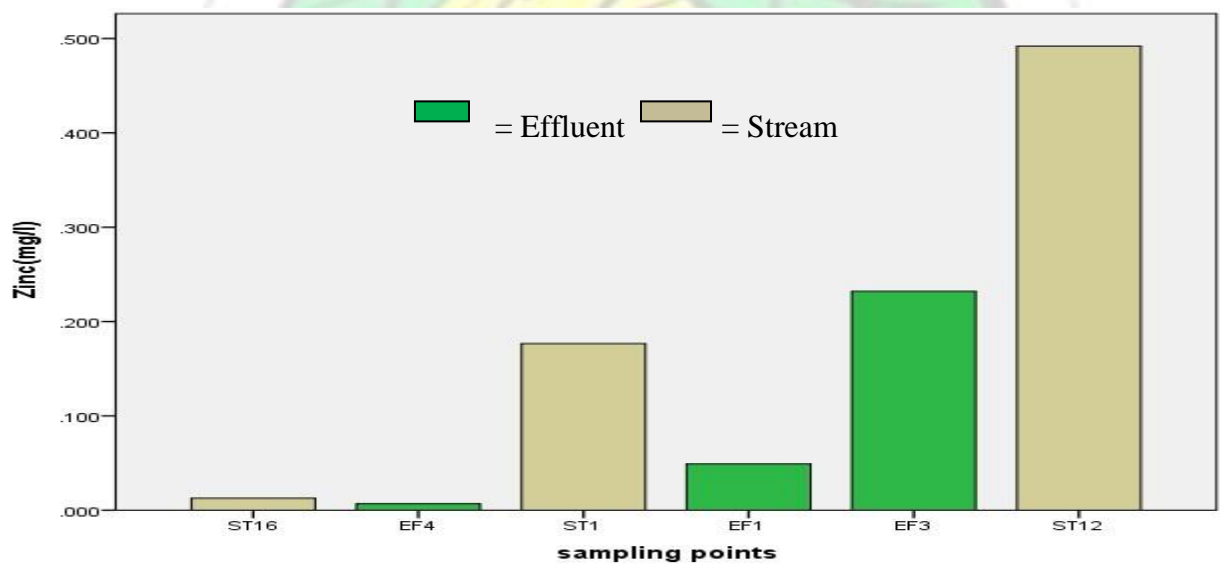
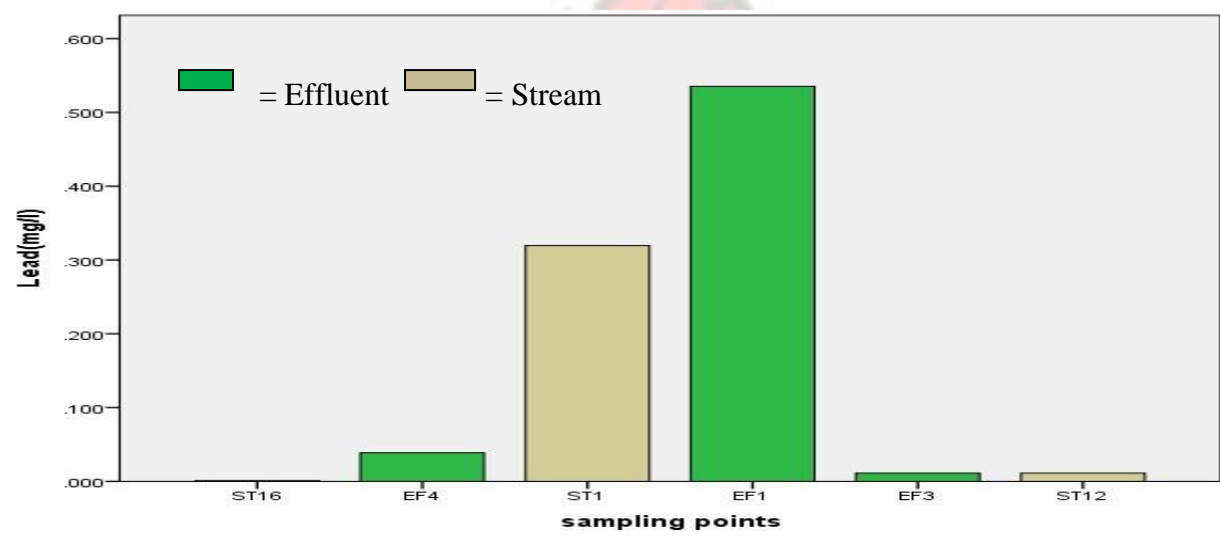
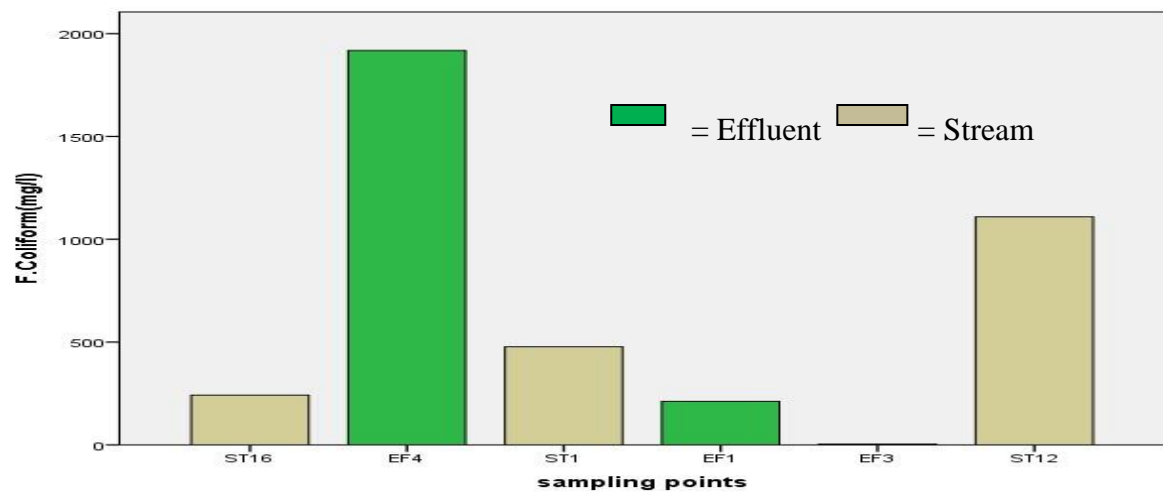
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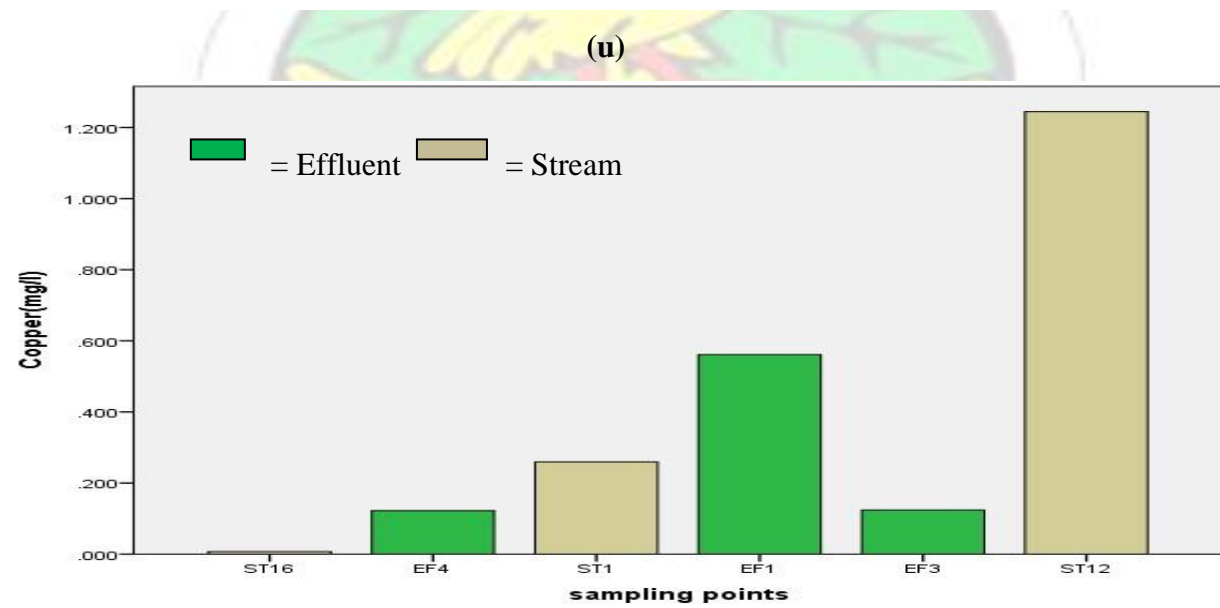
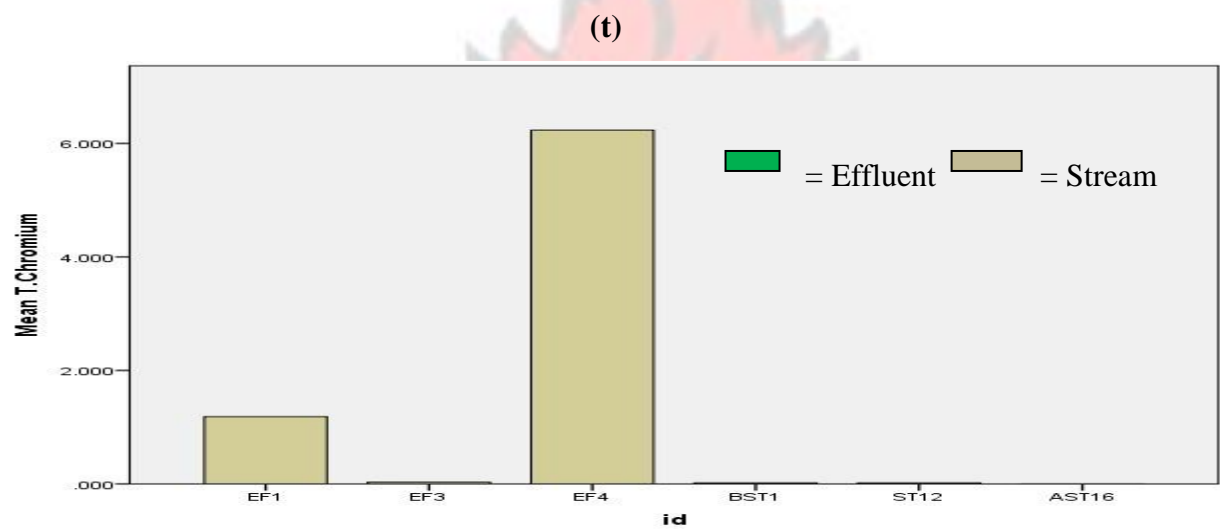
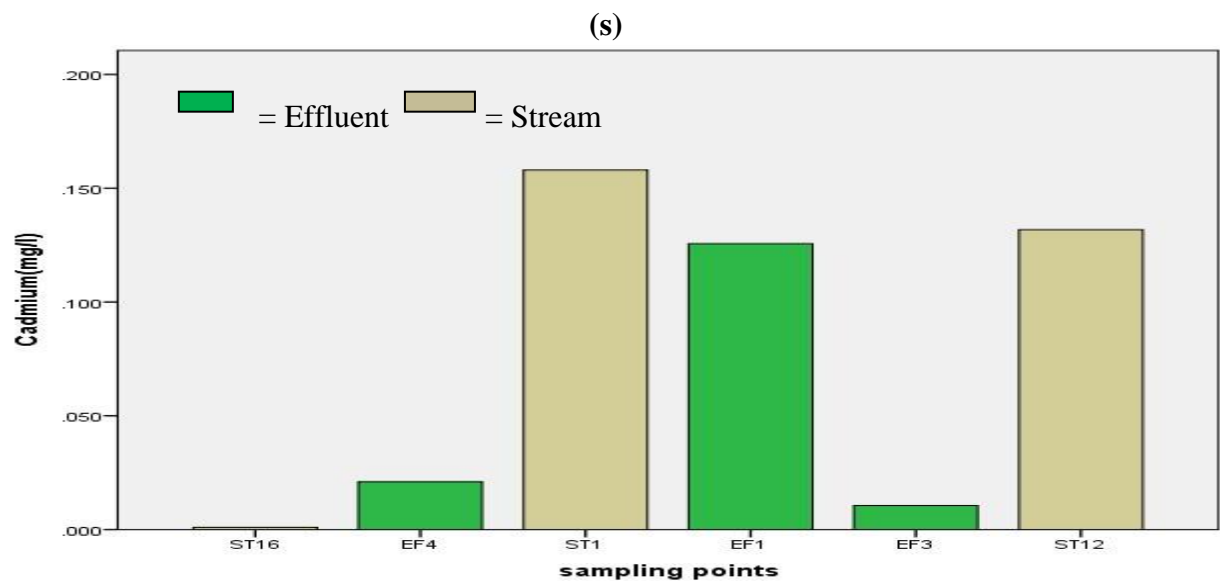


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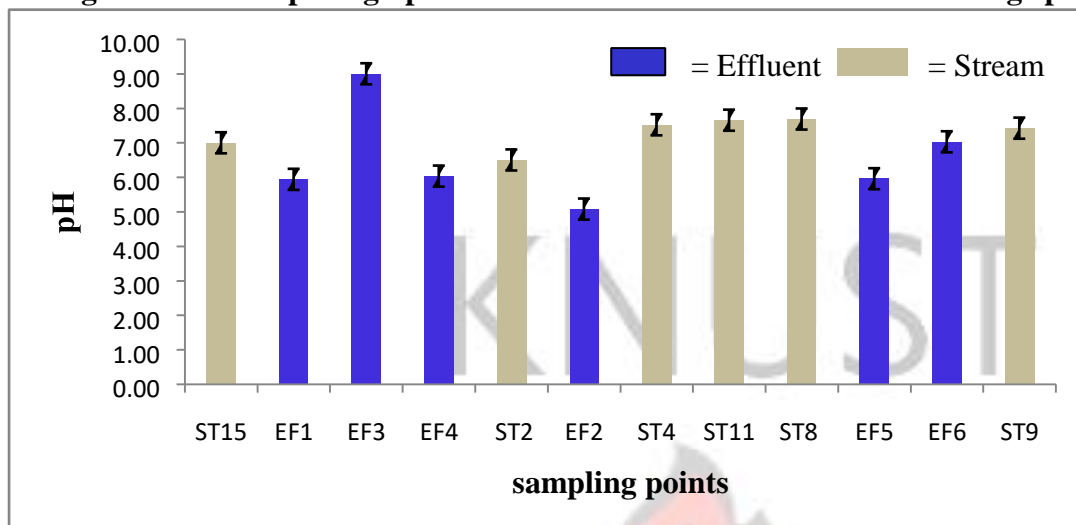
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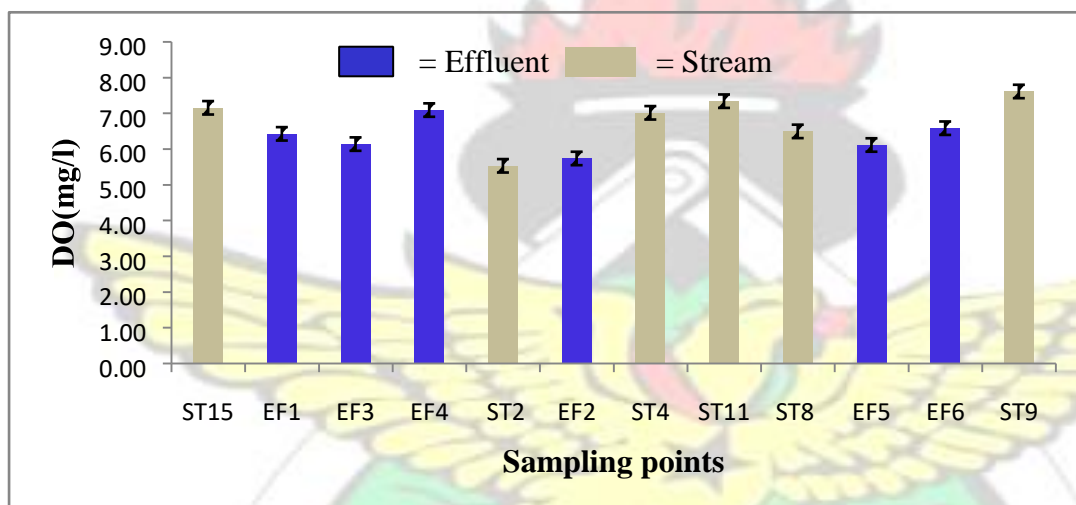


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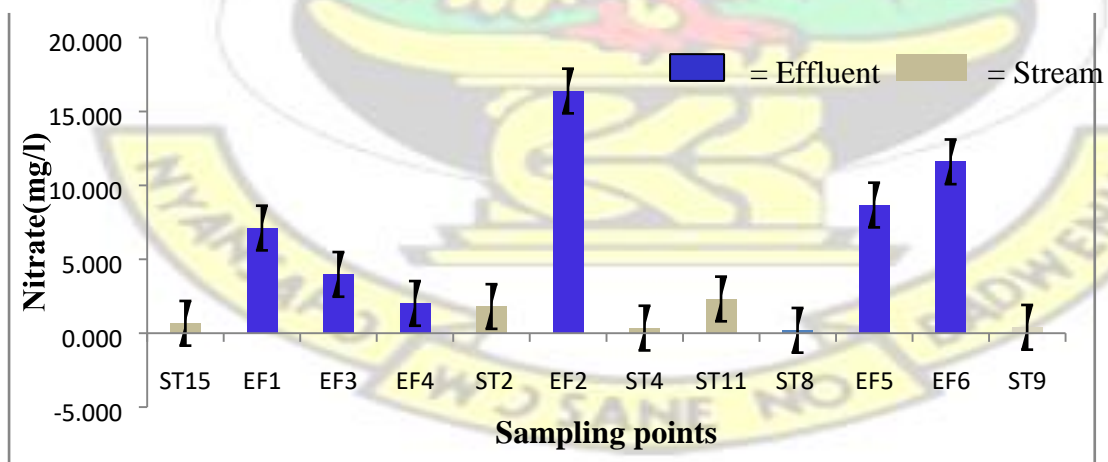
Figures 5.2: Comparing upstream and downstream after each discharge point main stream

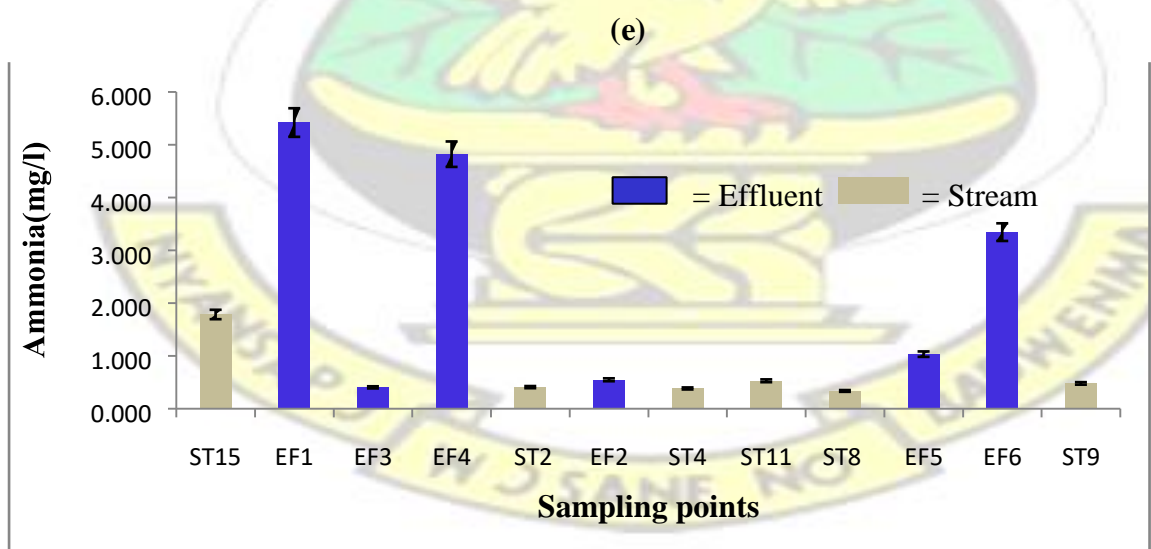
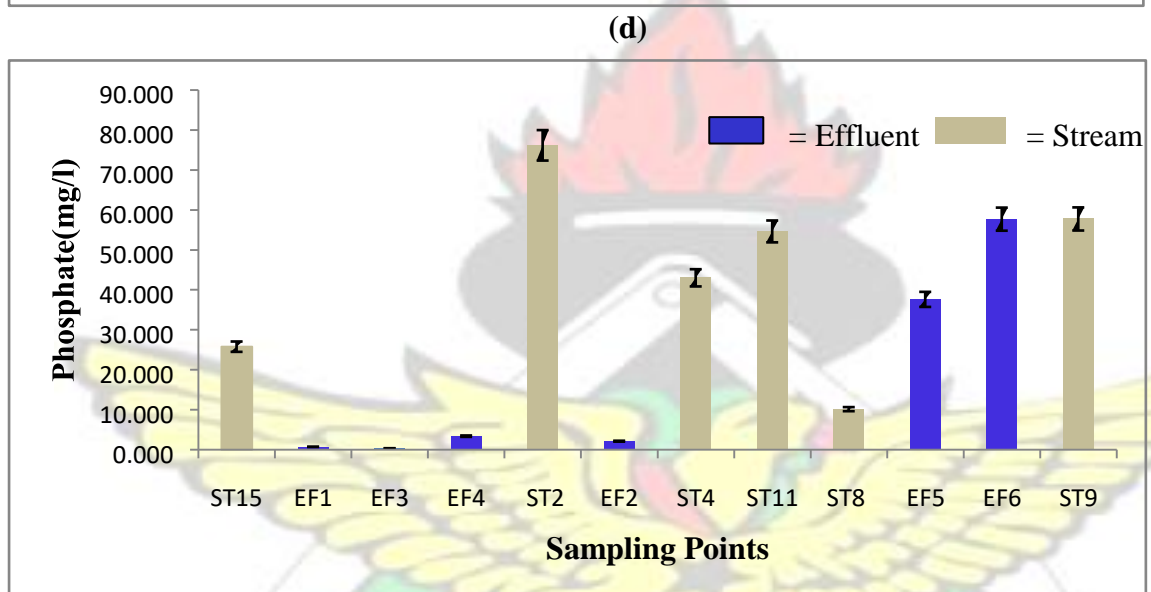
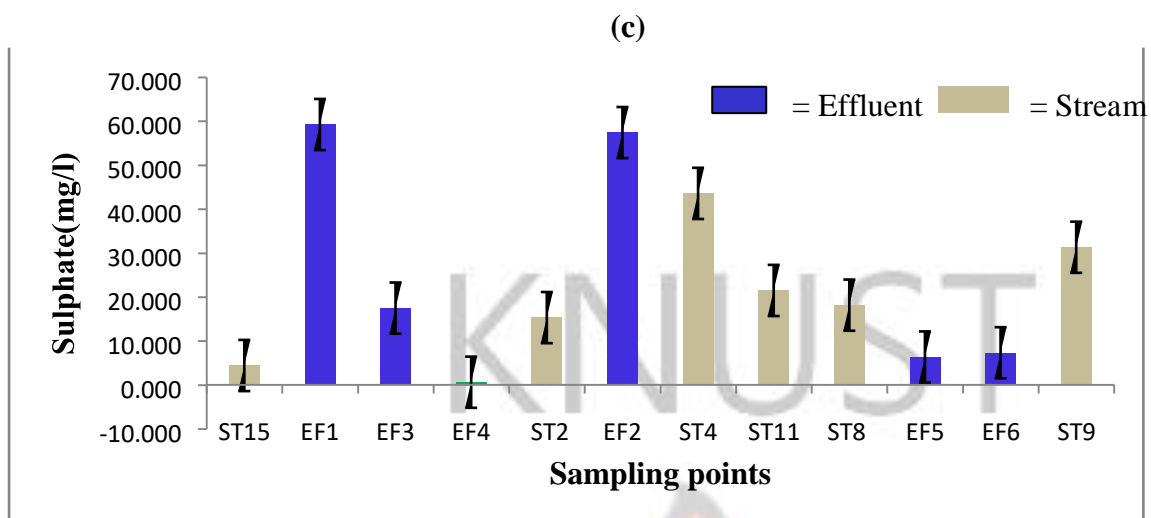


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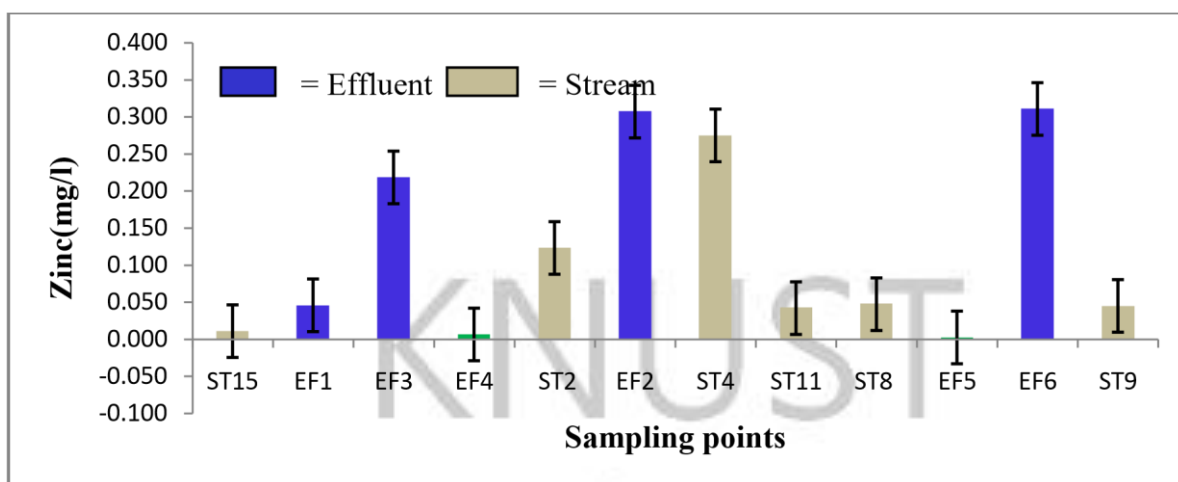


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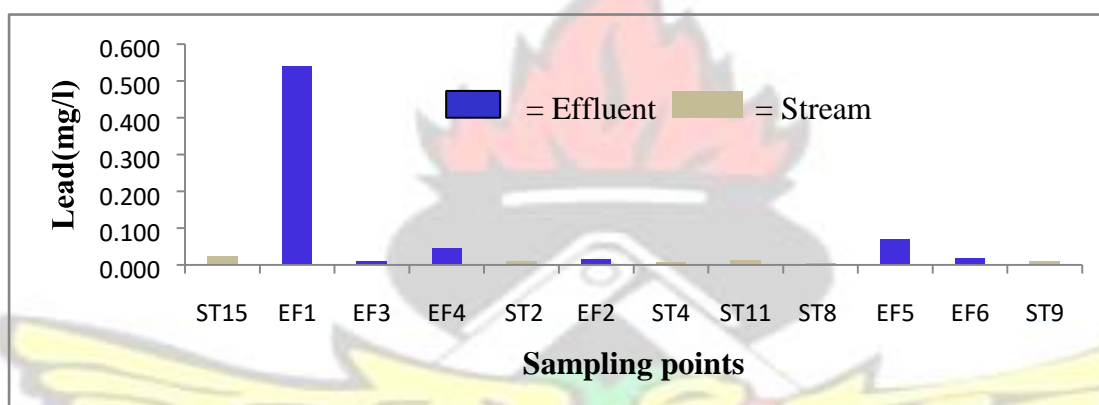




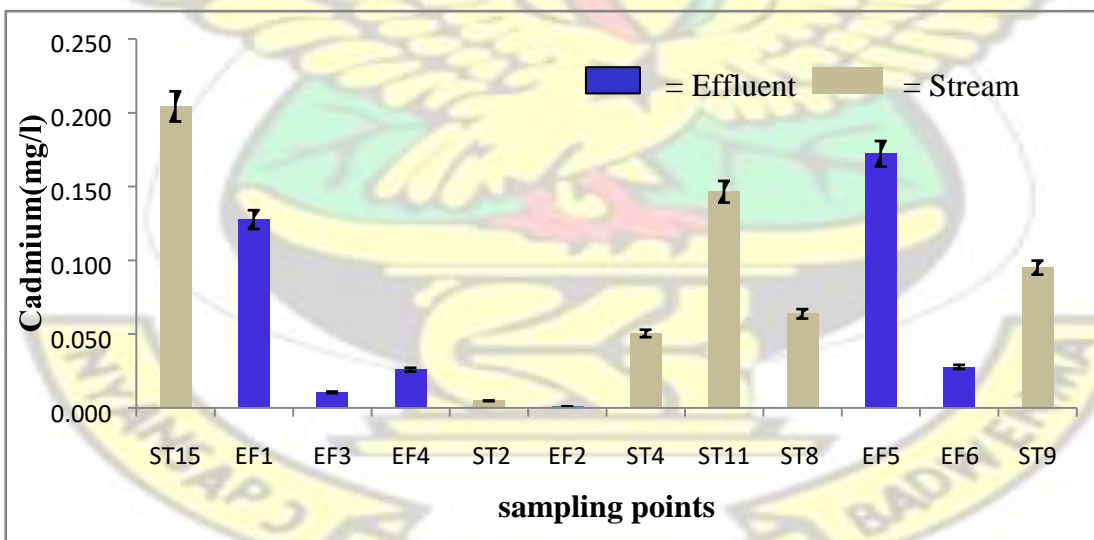
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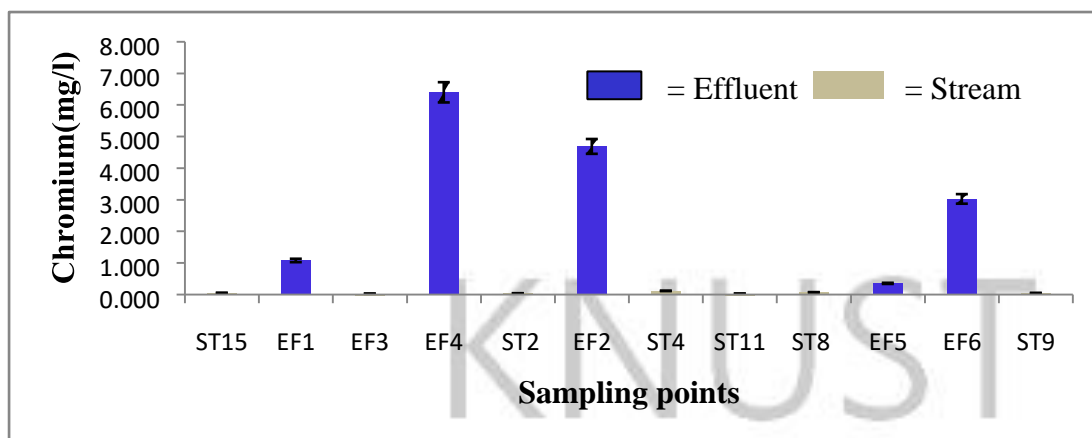
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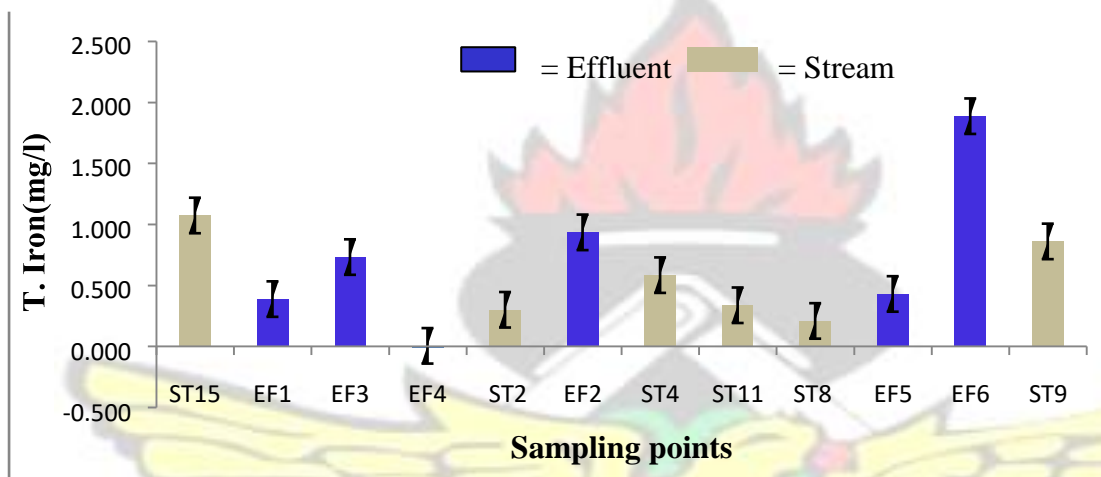
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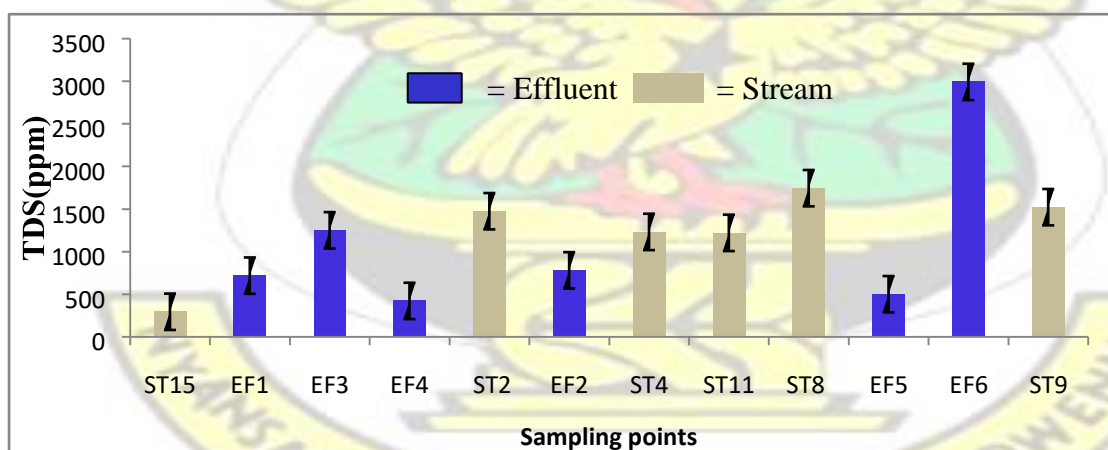
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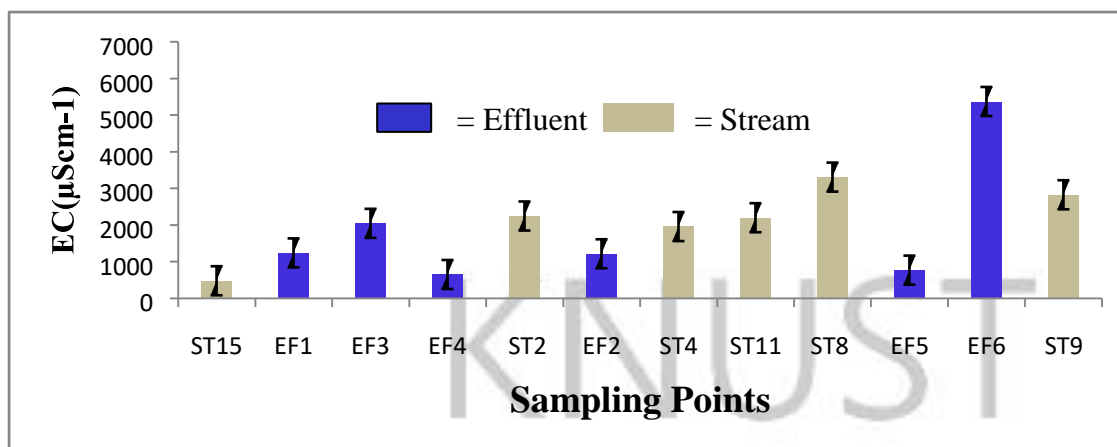
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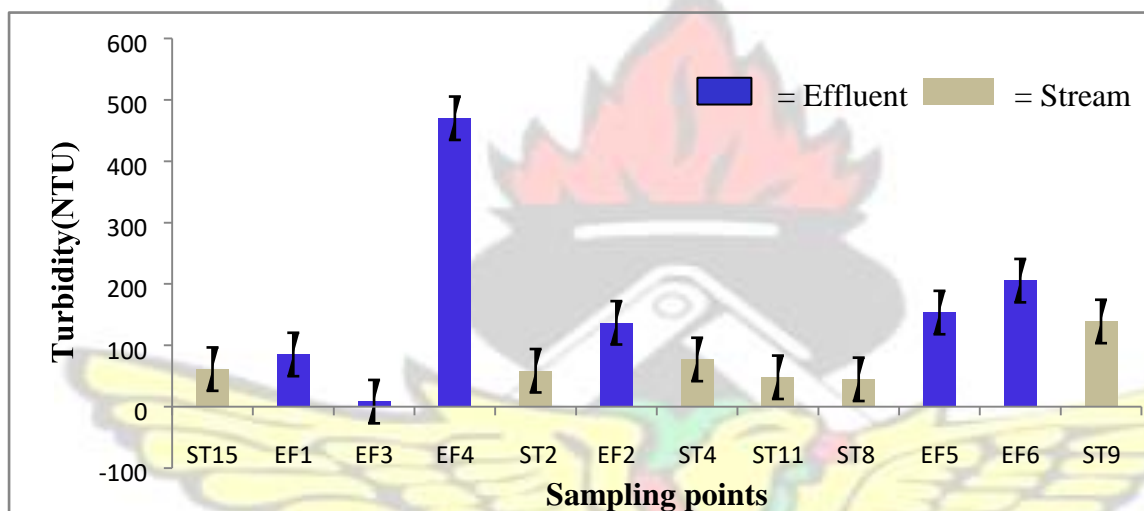
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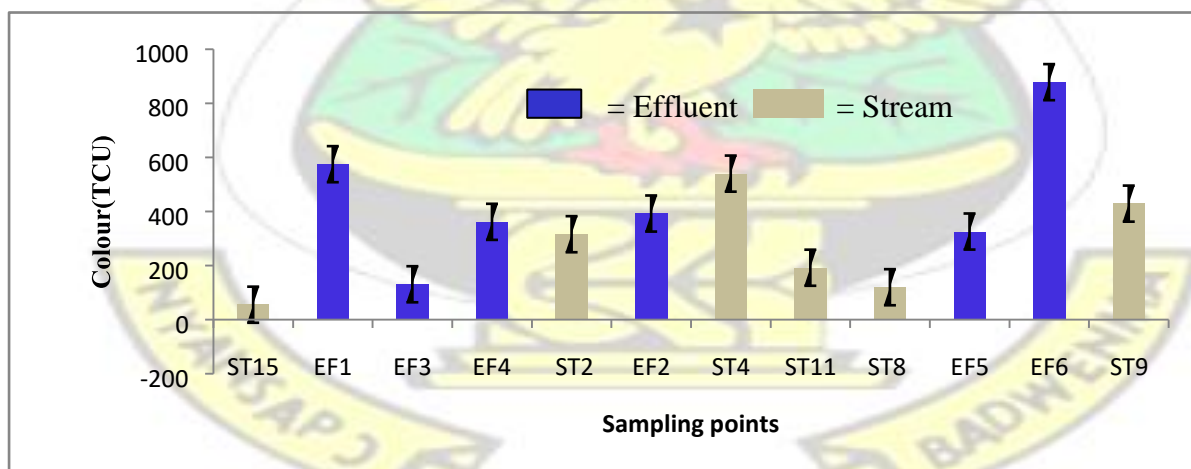
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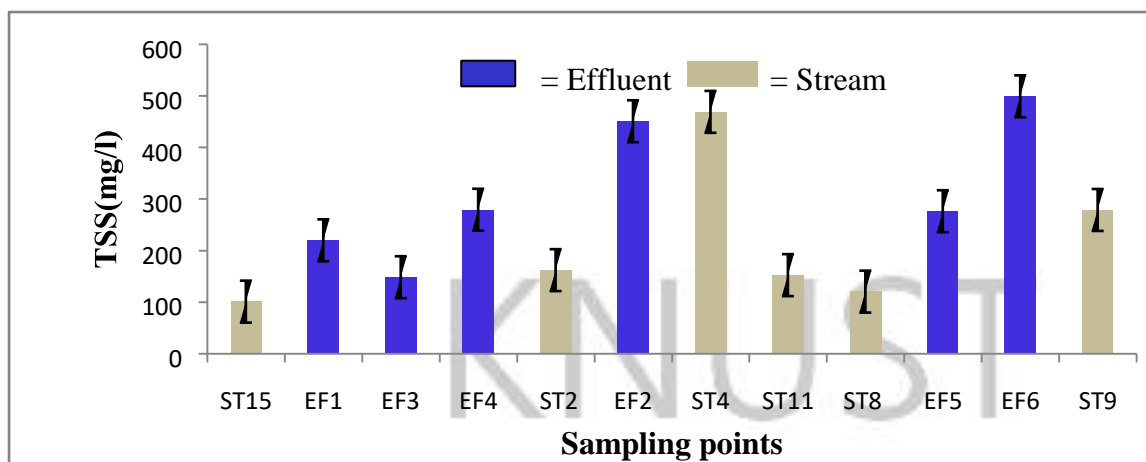
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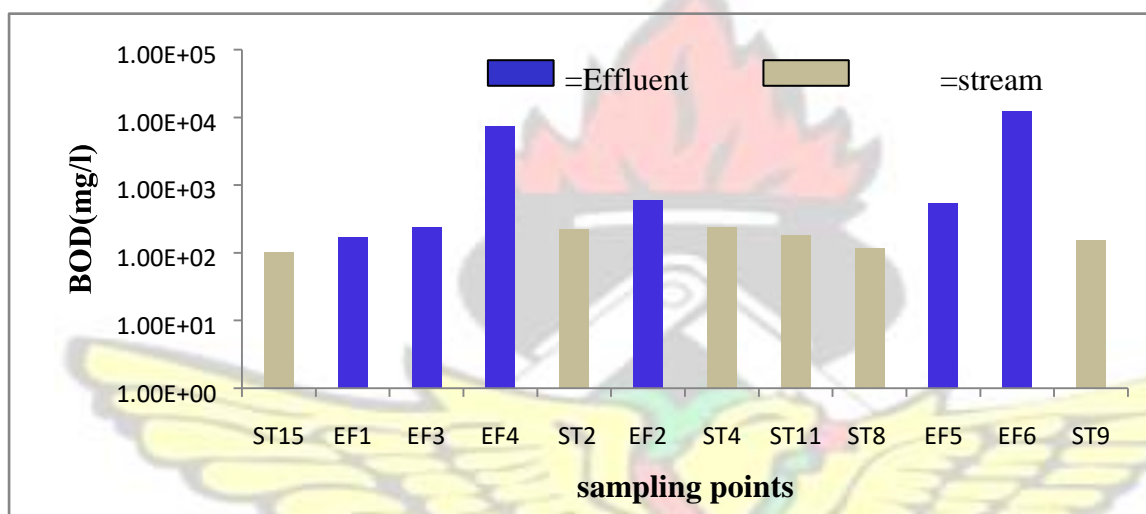
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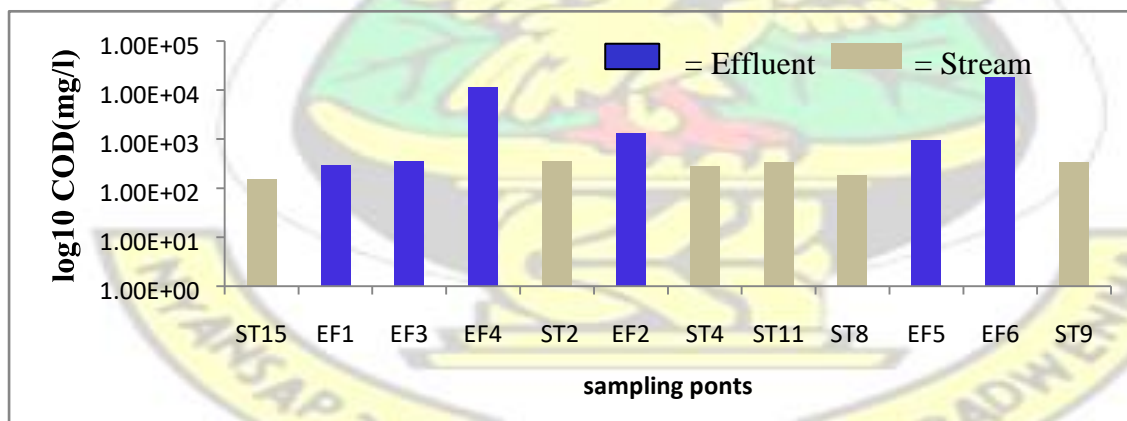
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(p)

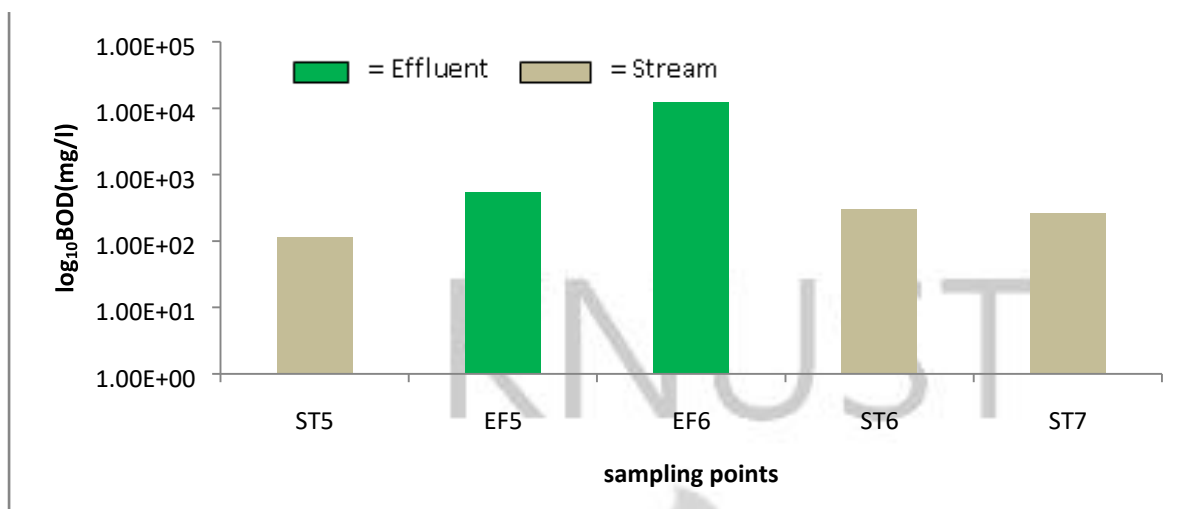


(q)

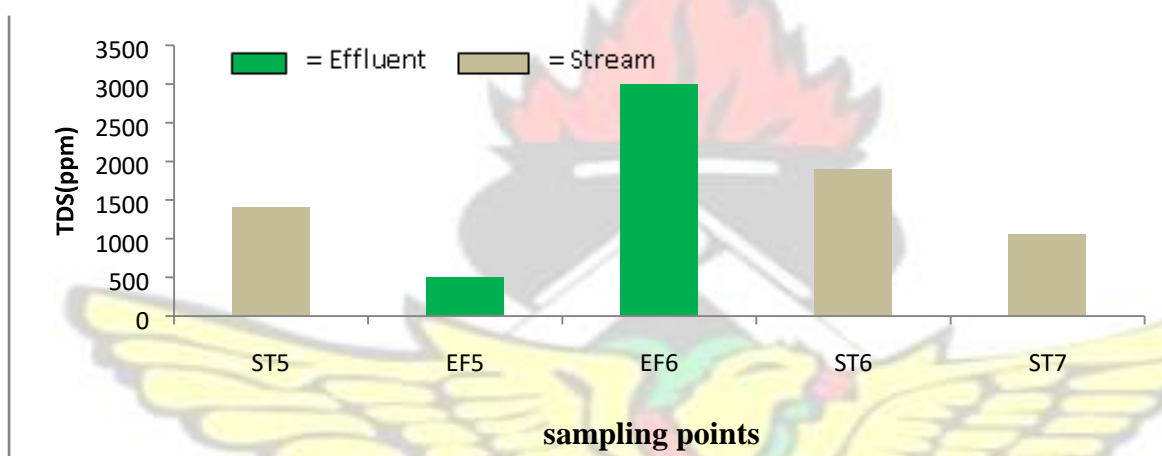


(r)

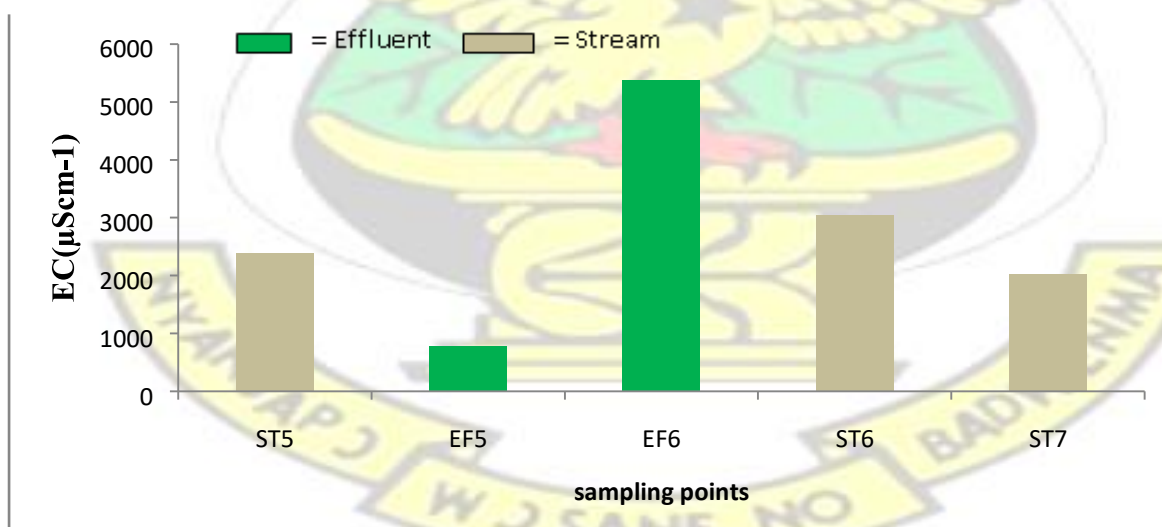
Figures 5.3: Comparing the Upstream and Downstream after each discharge point (Motorway Tributaries)



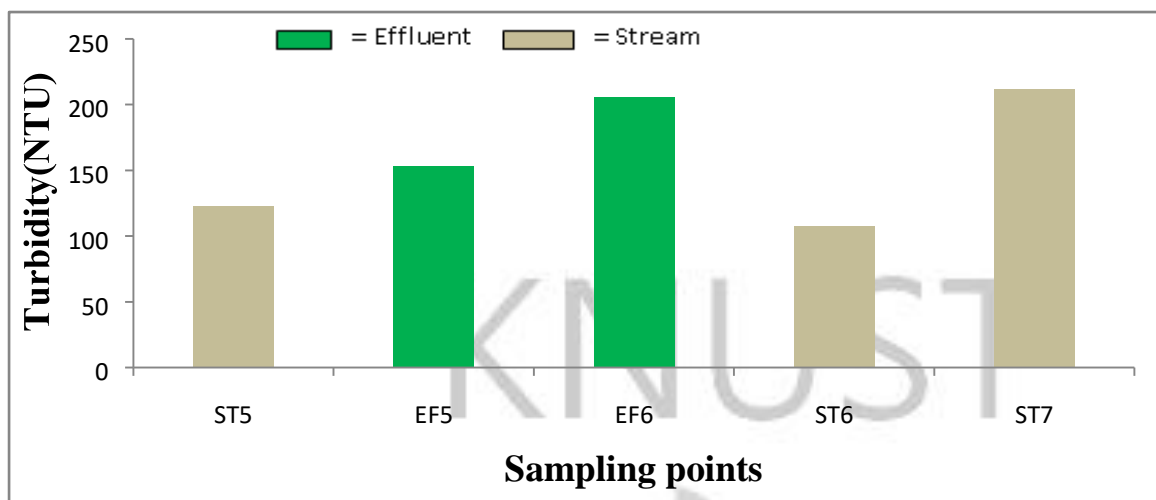
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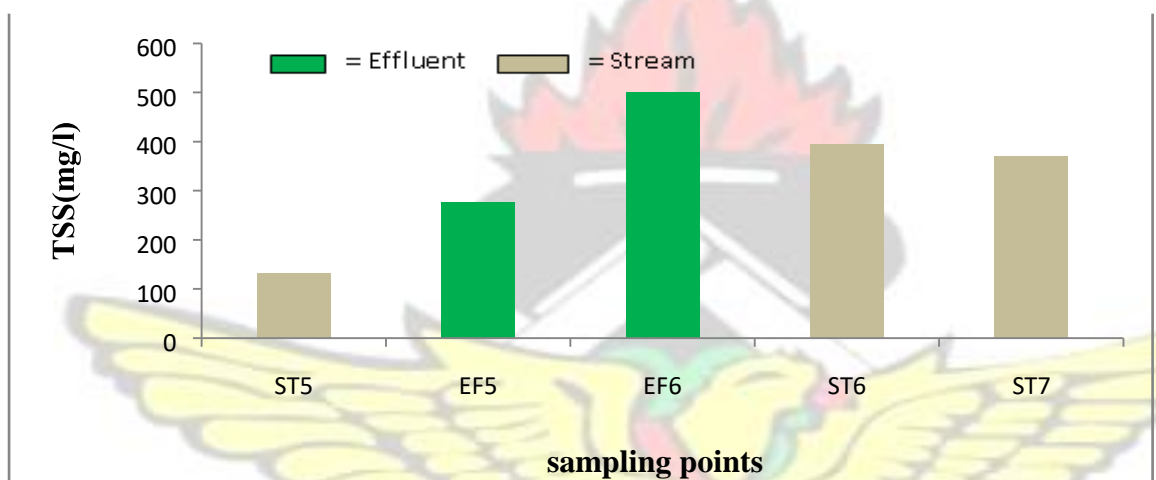
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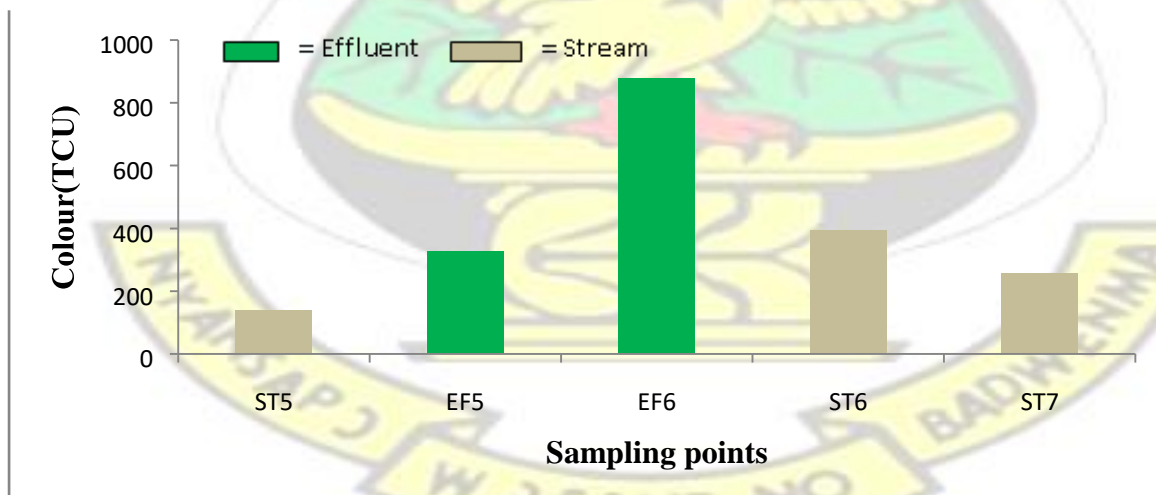
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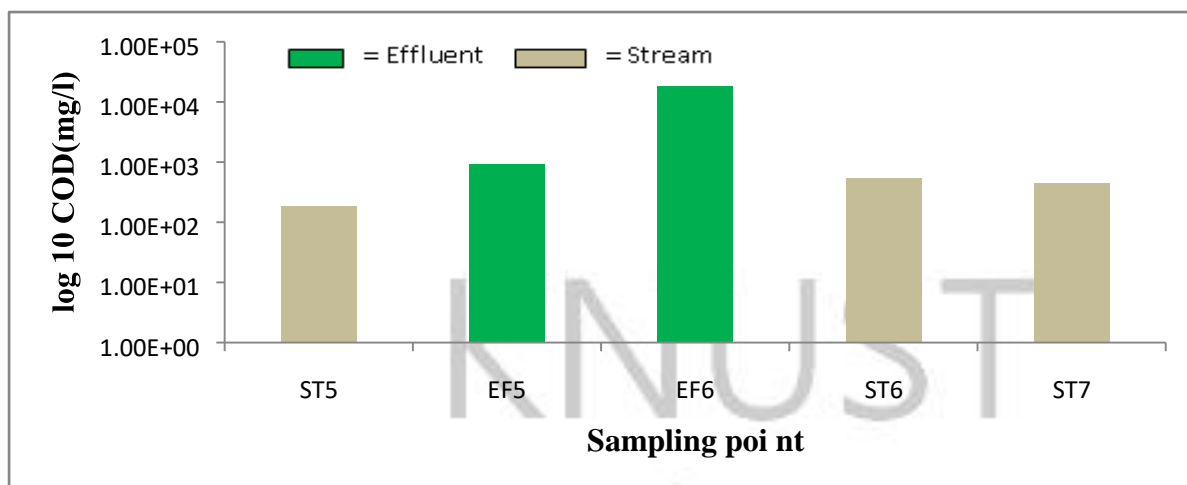
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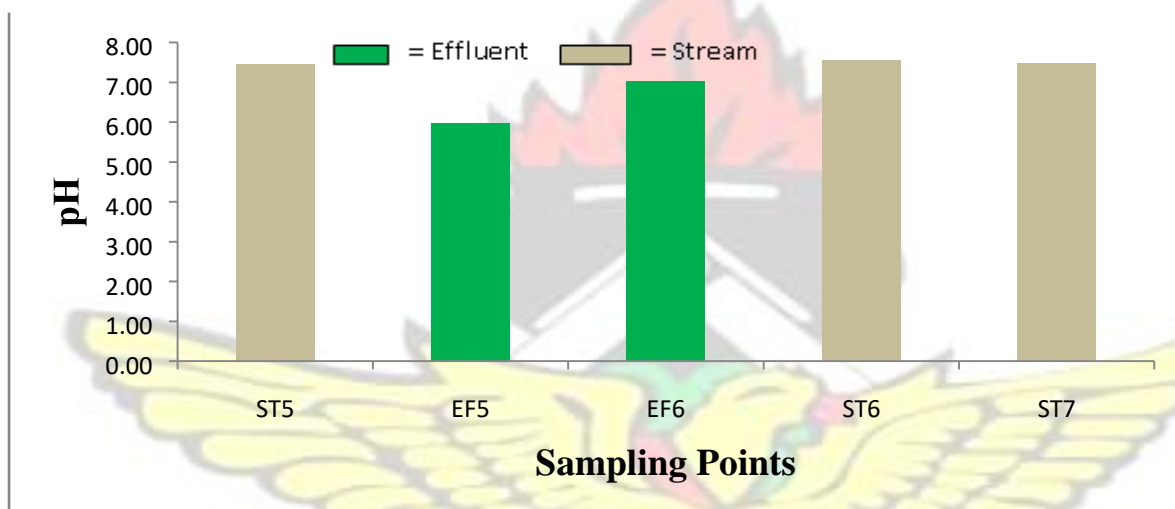
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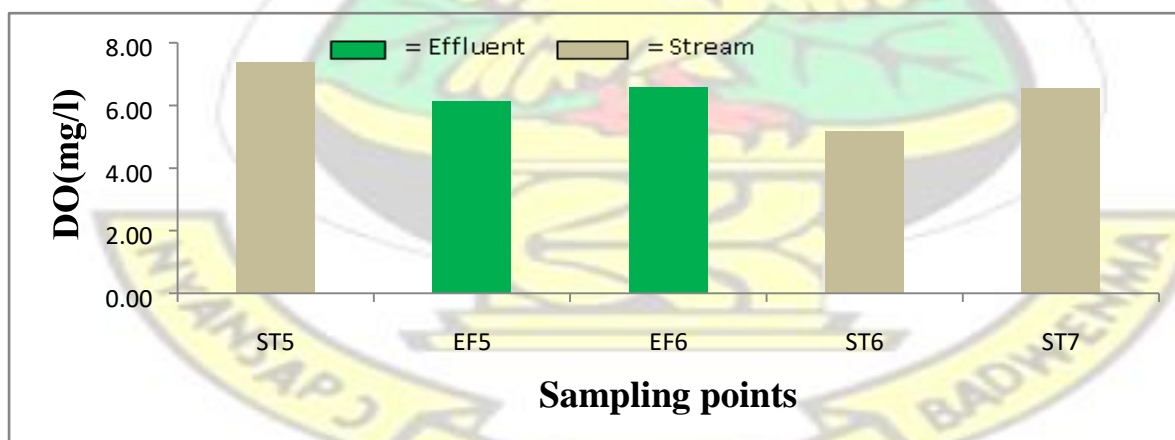
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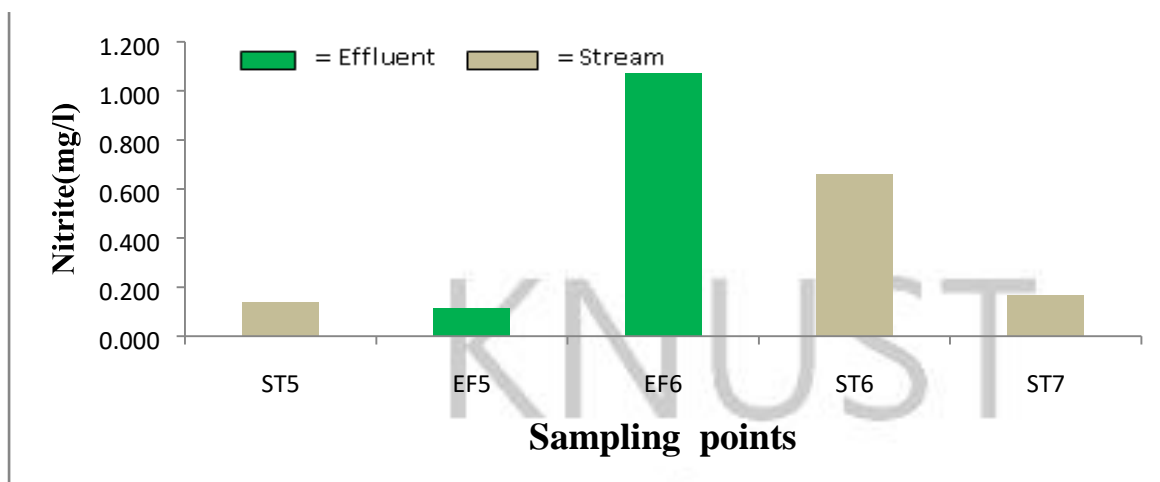
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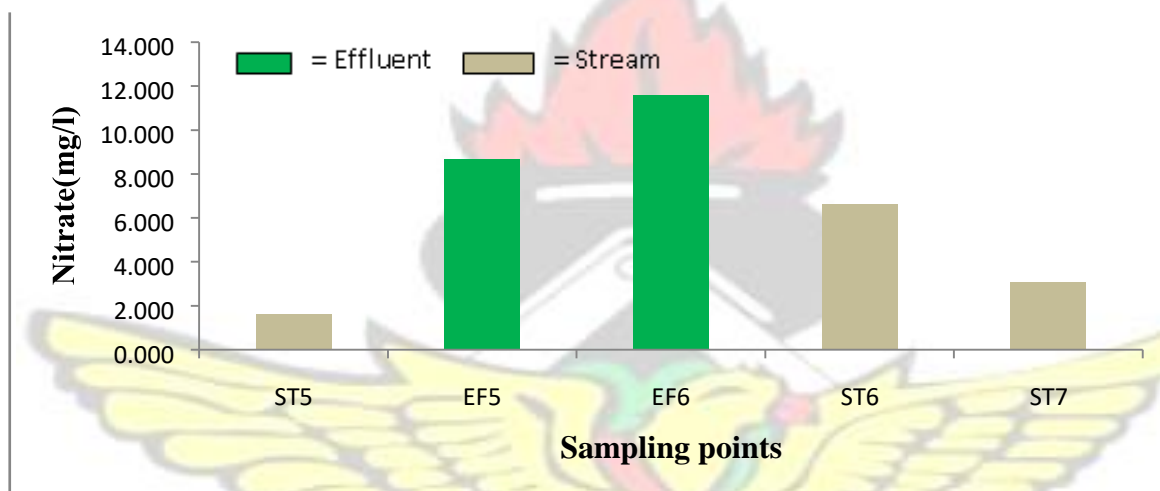
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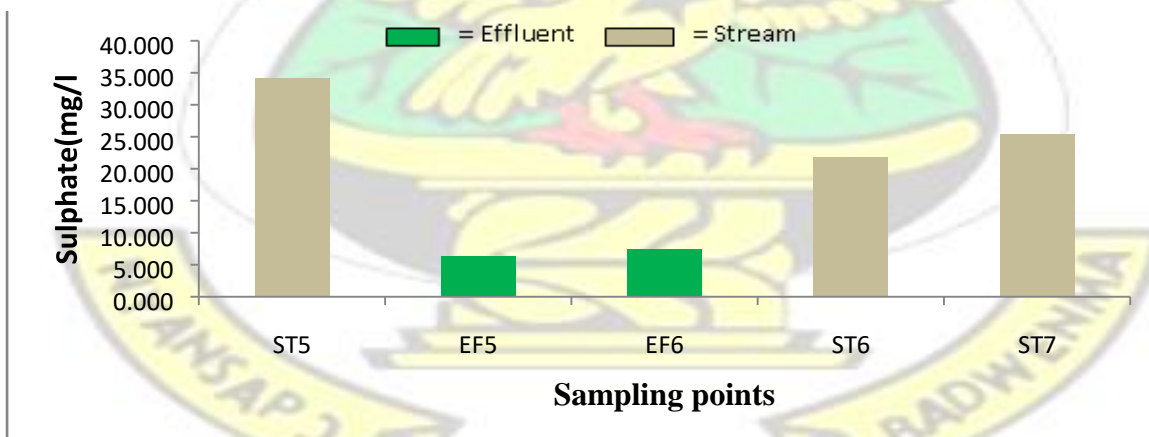
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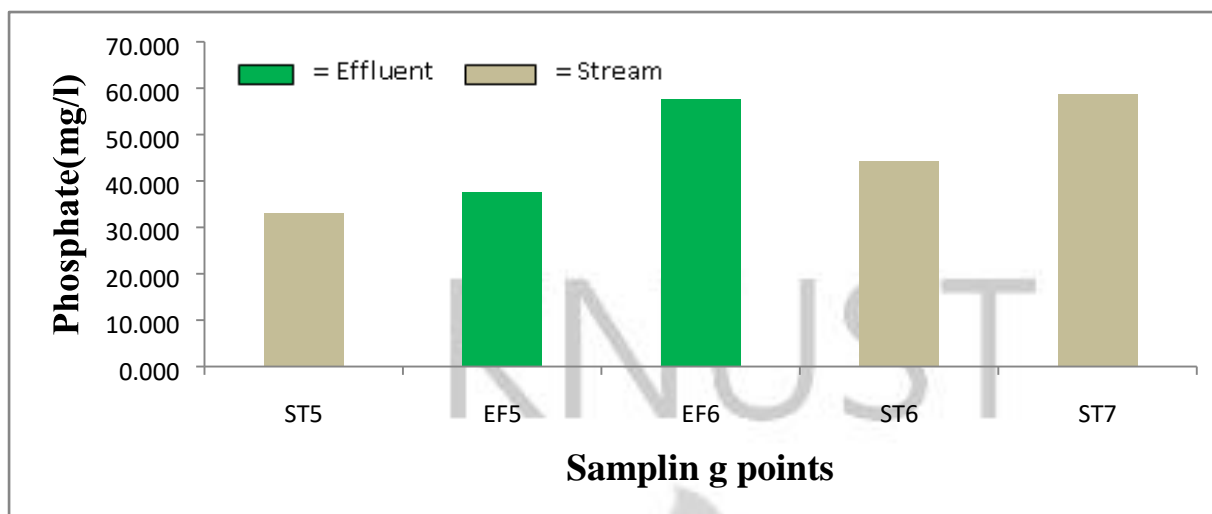
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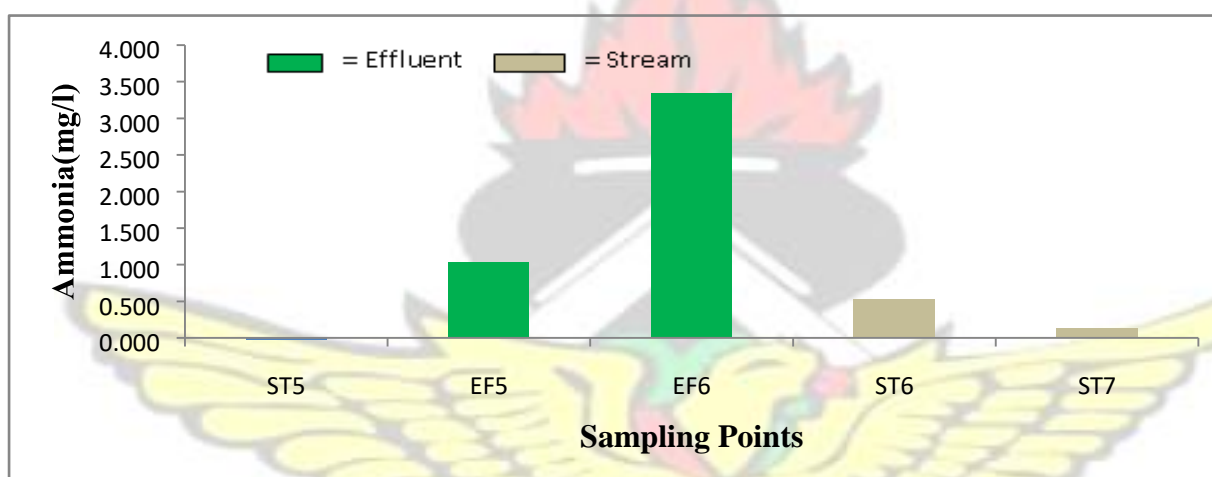
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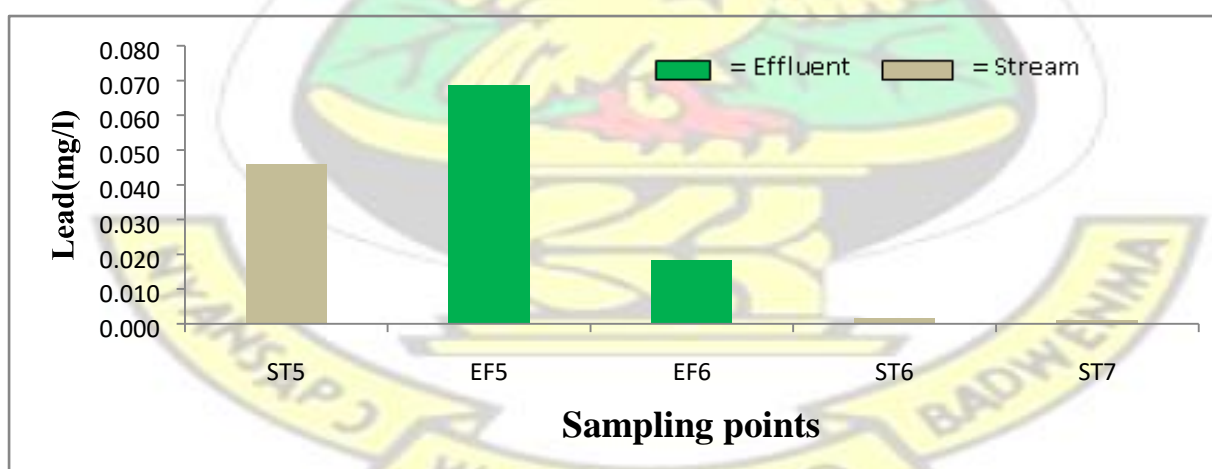
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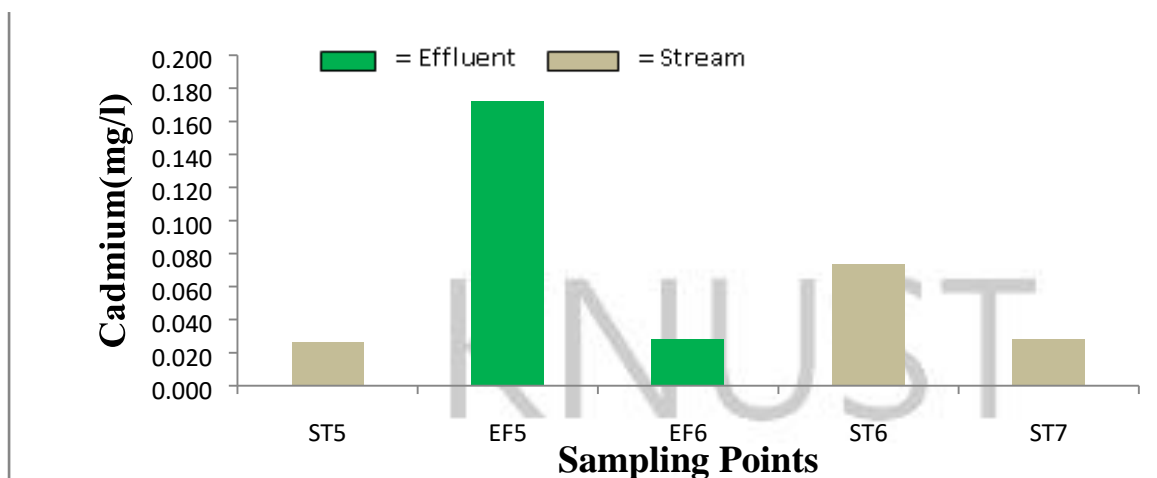
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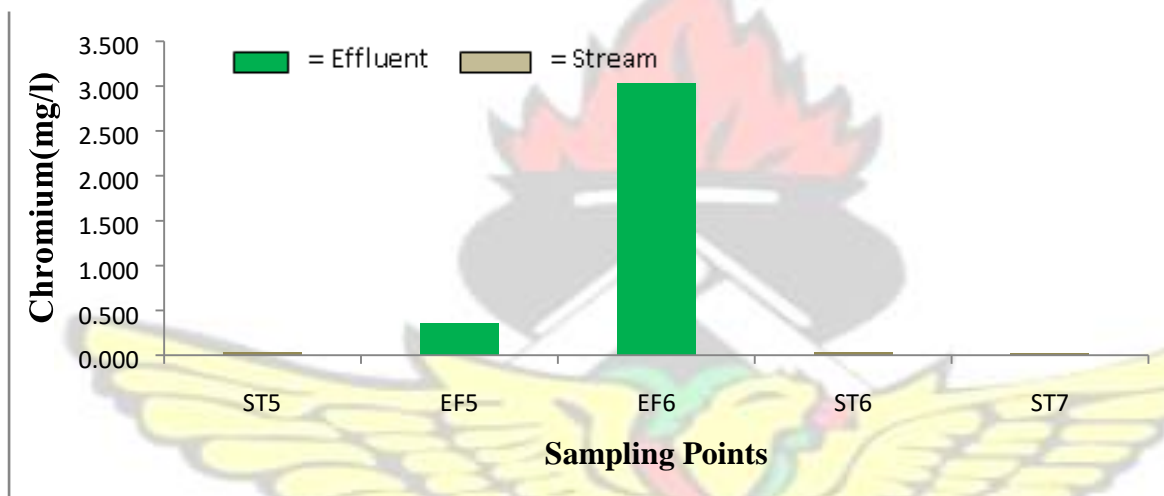
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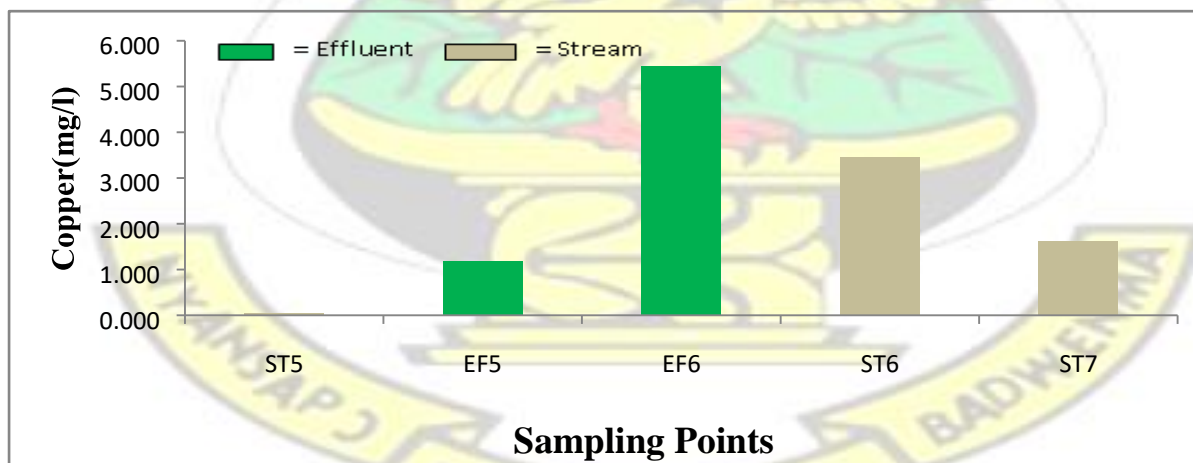
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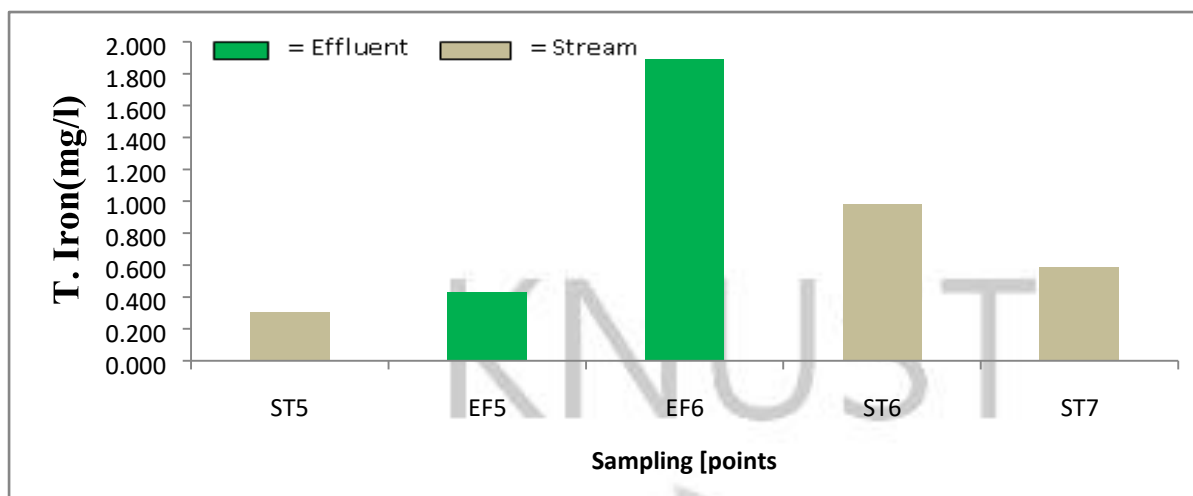
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(q)

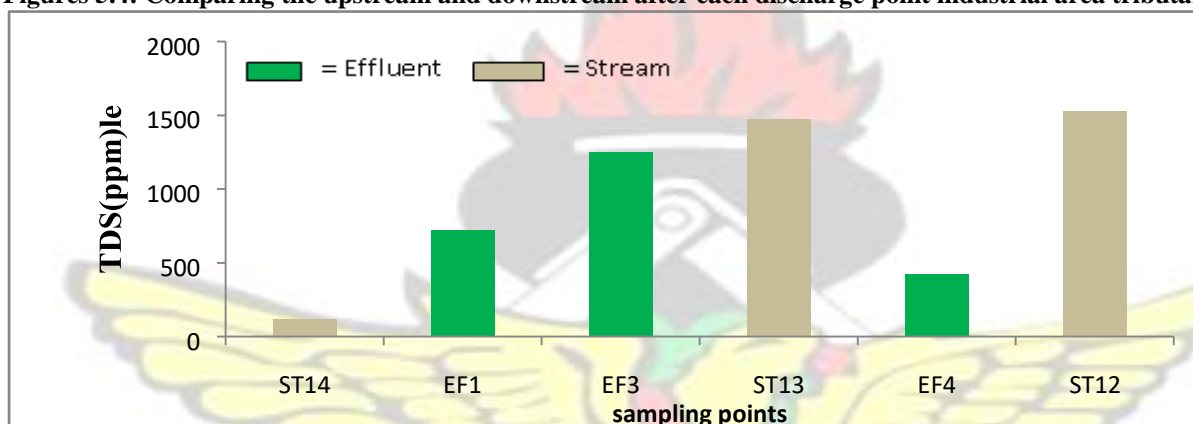


(r)

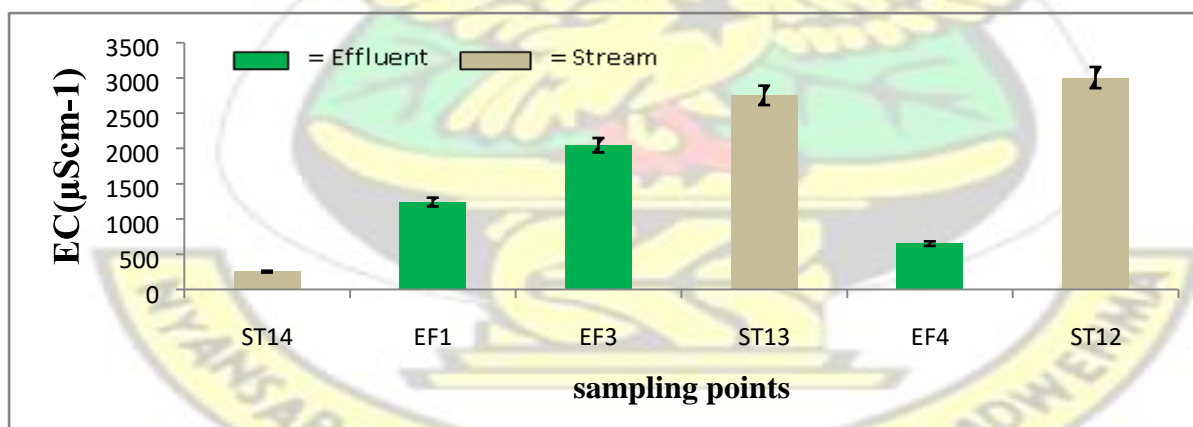


(s)

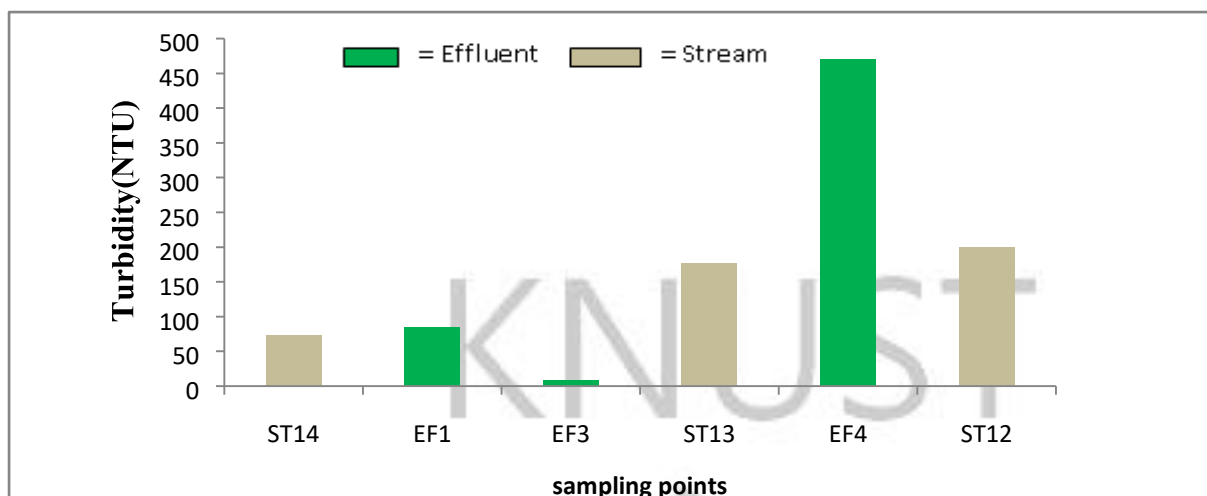
Figures 5.4: Comparing the upstream and downstream after each discharge point industrial area tributary



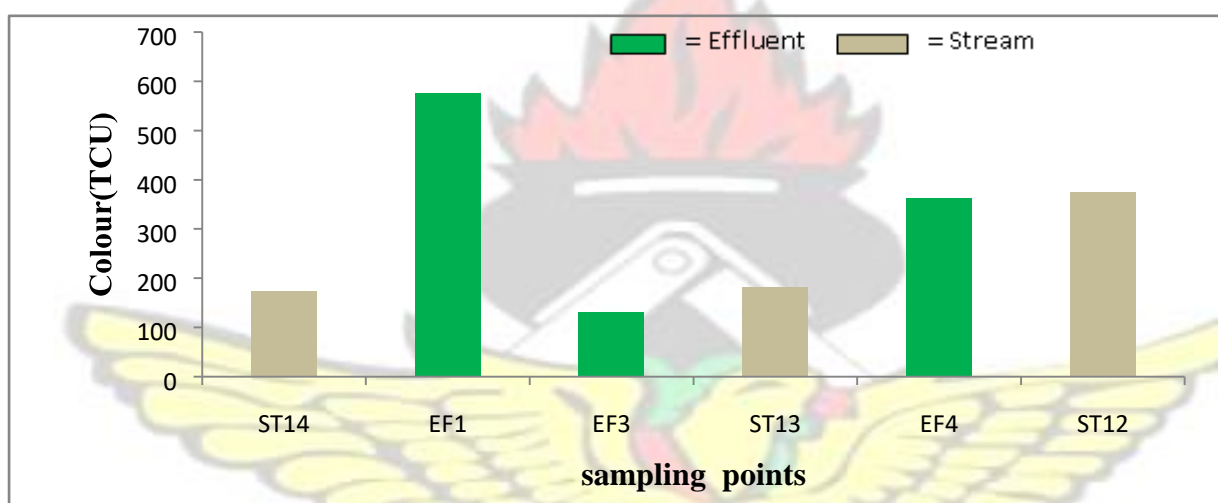
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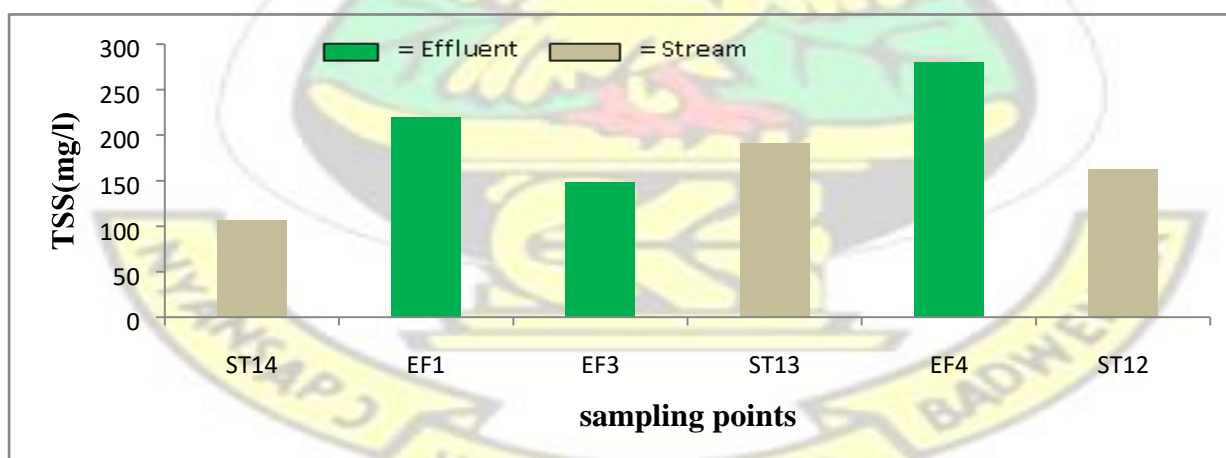
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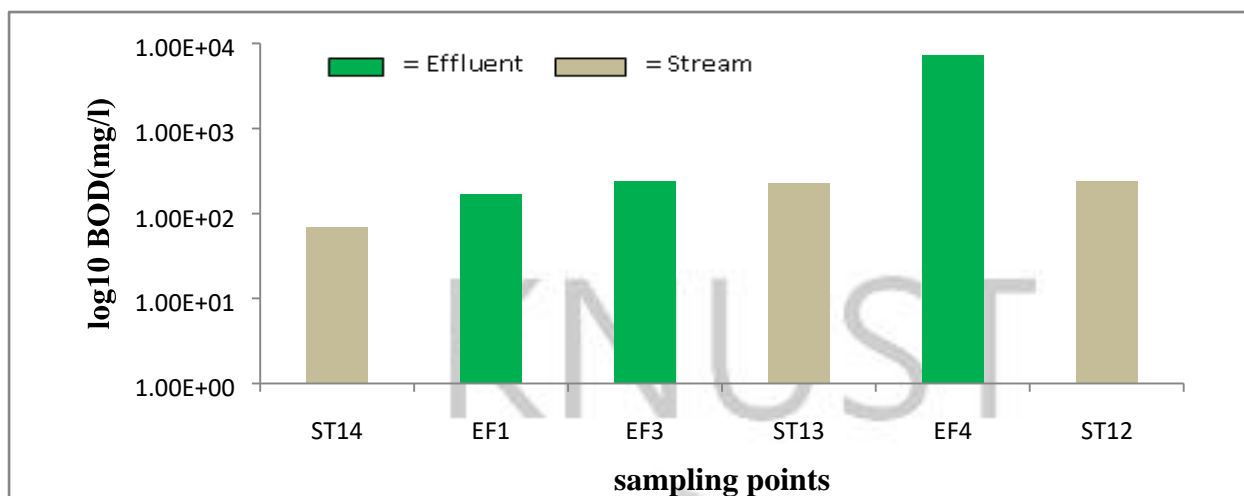
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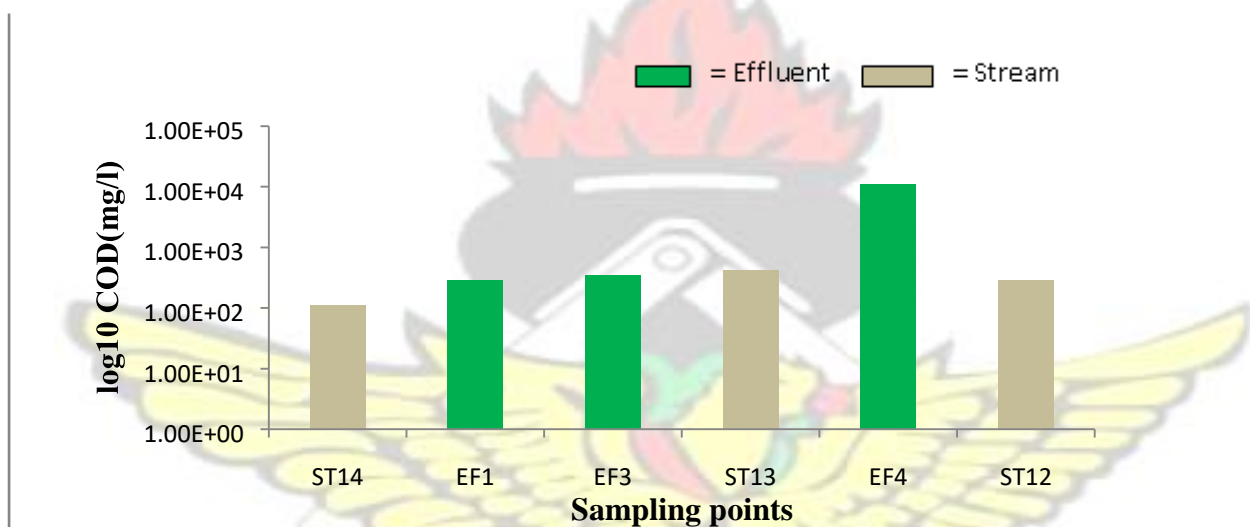
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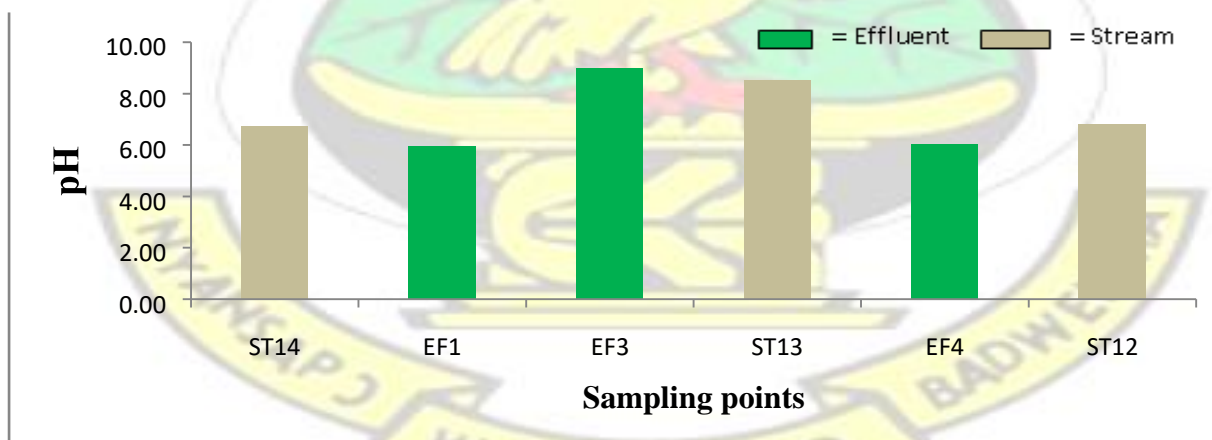
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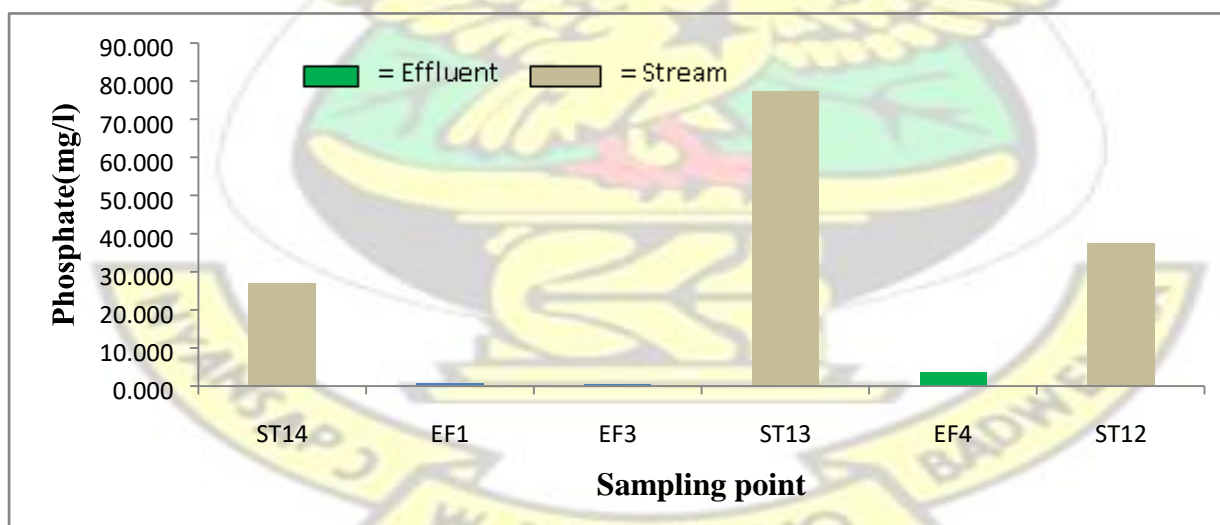
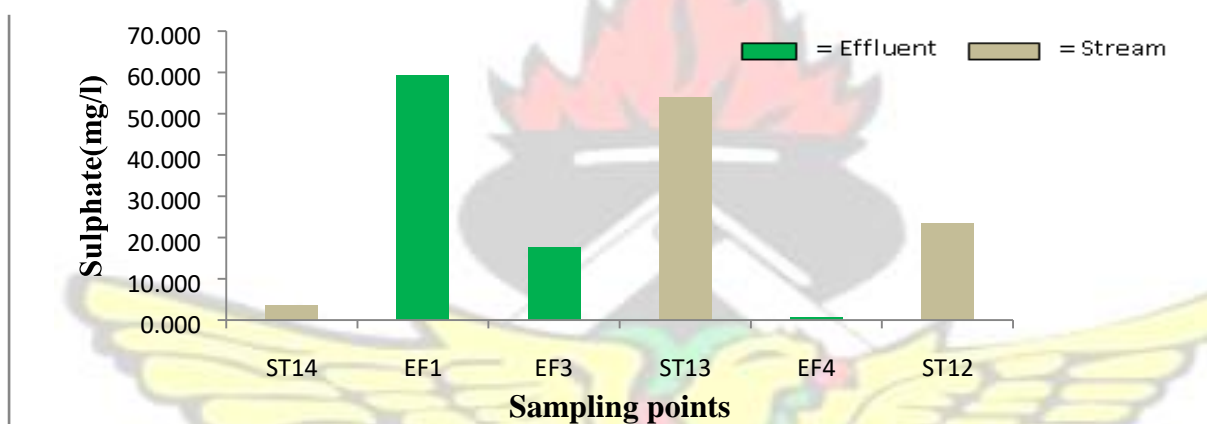
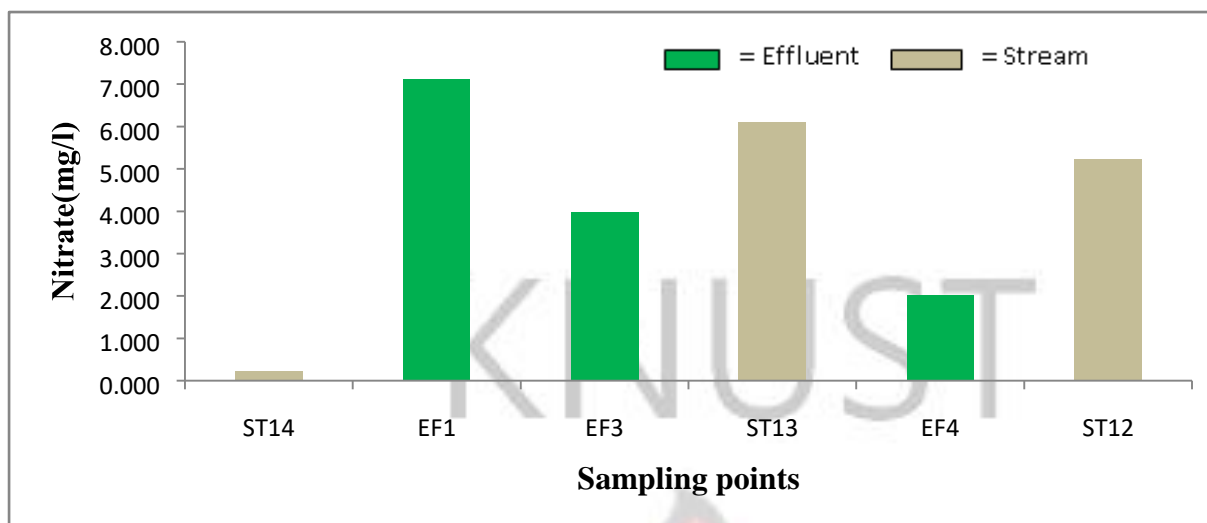
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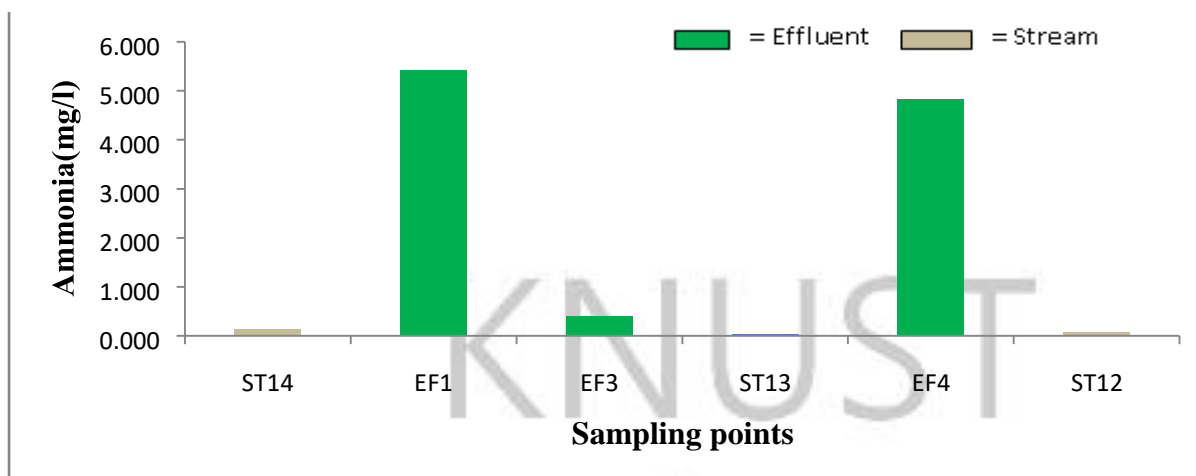


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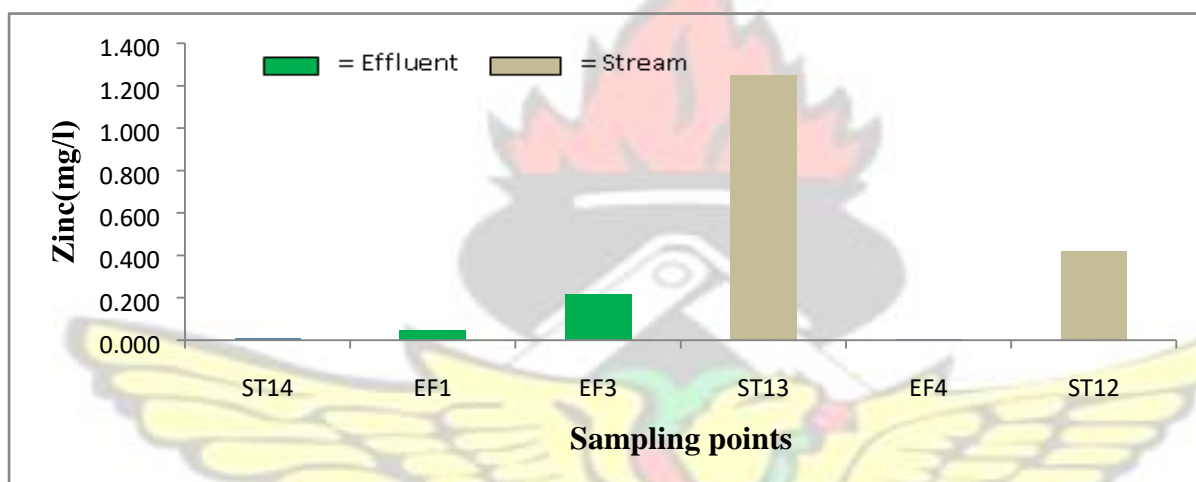


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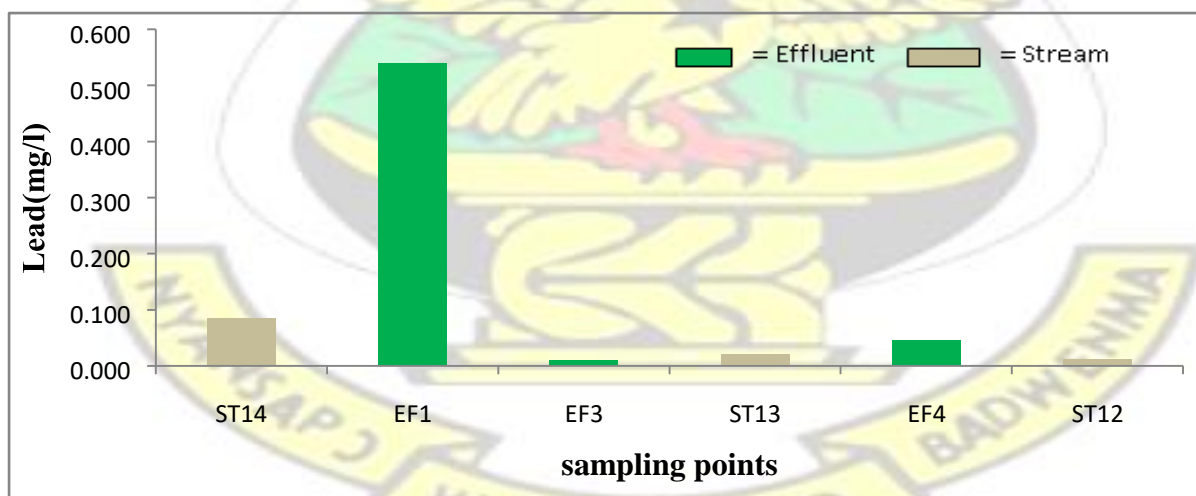




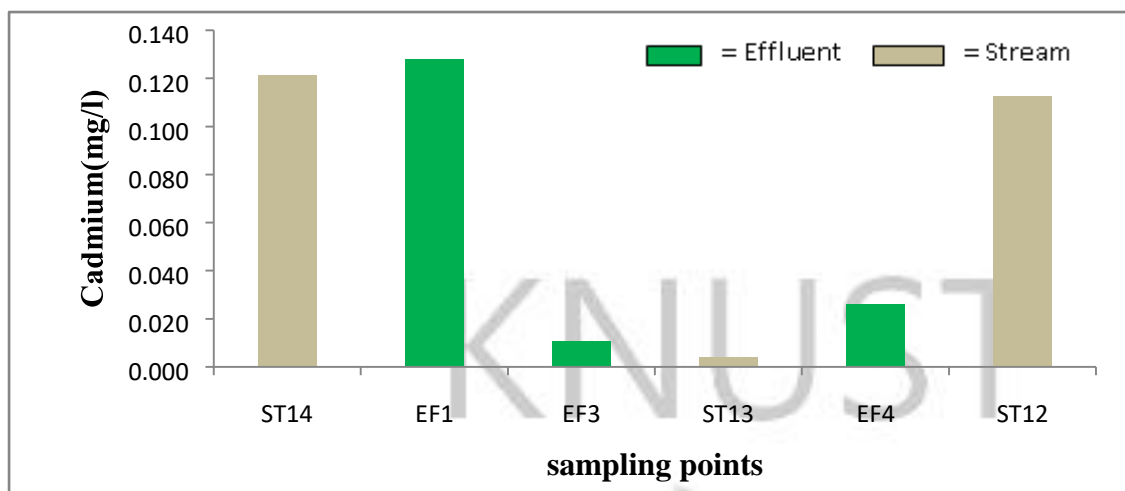
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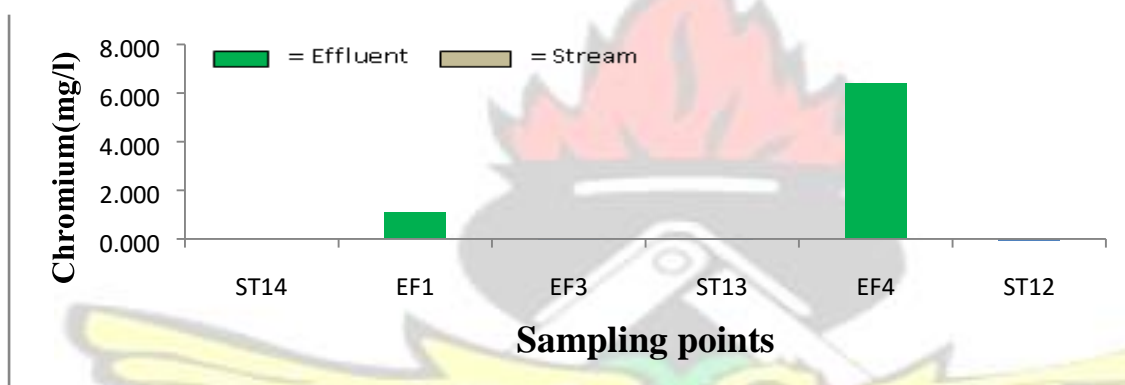
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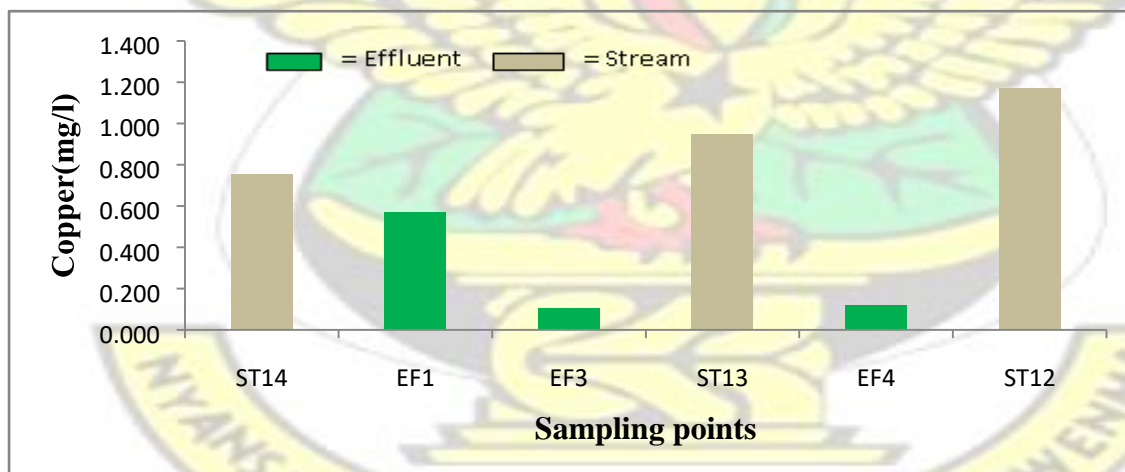
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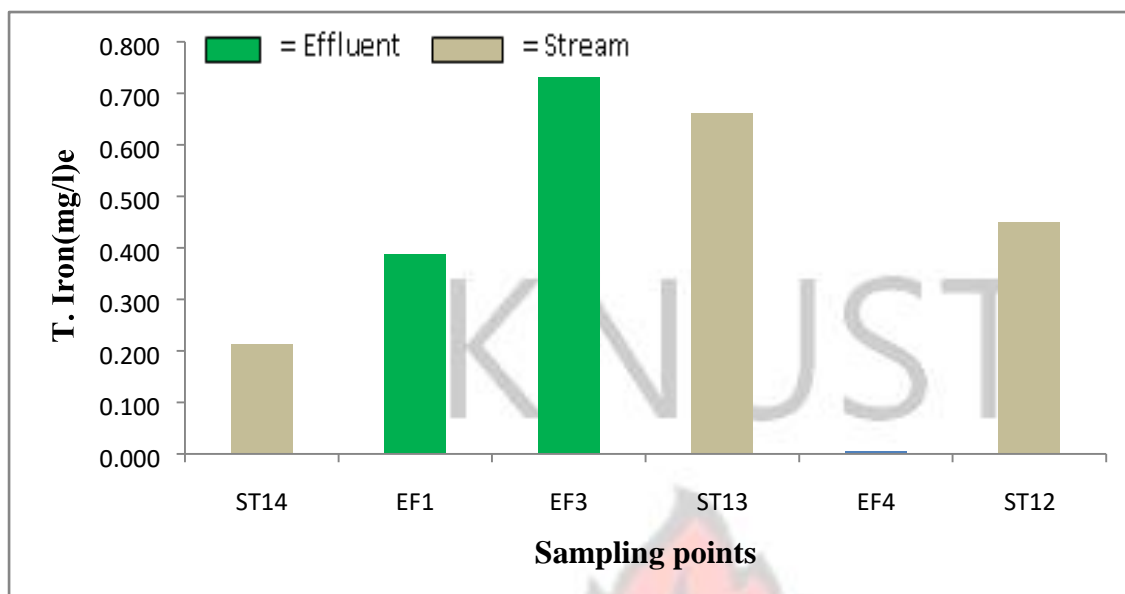
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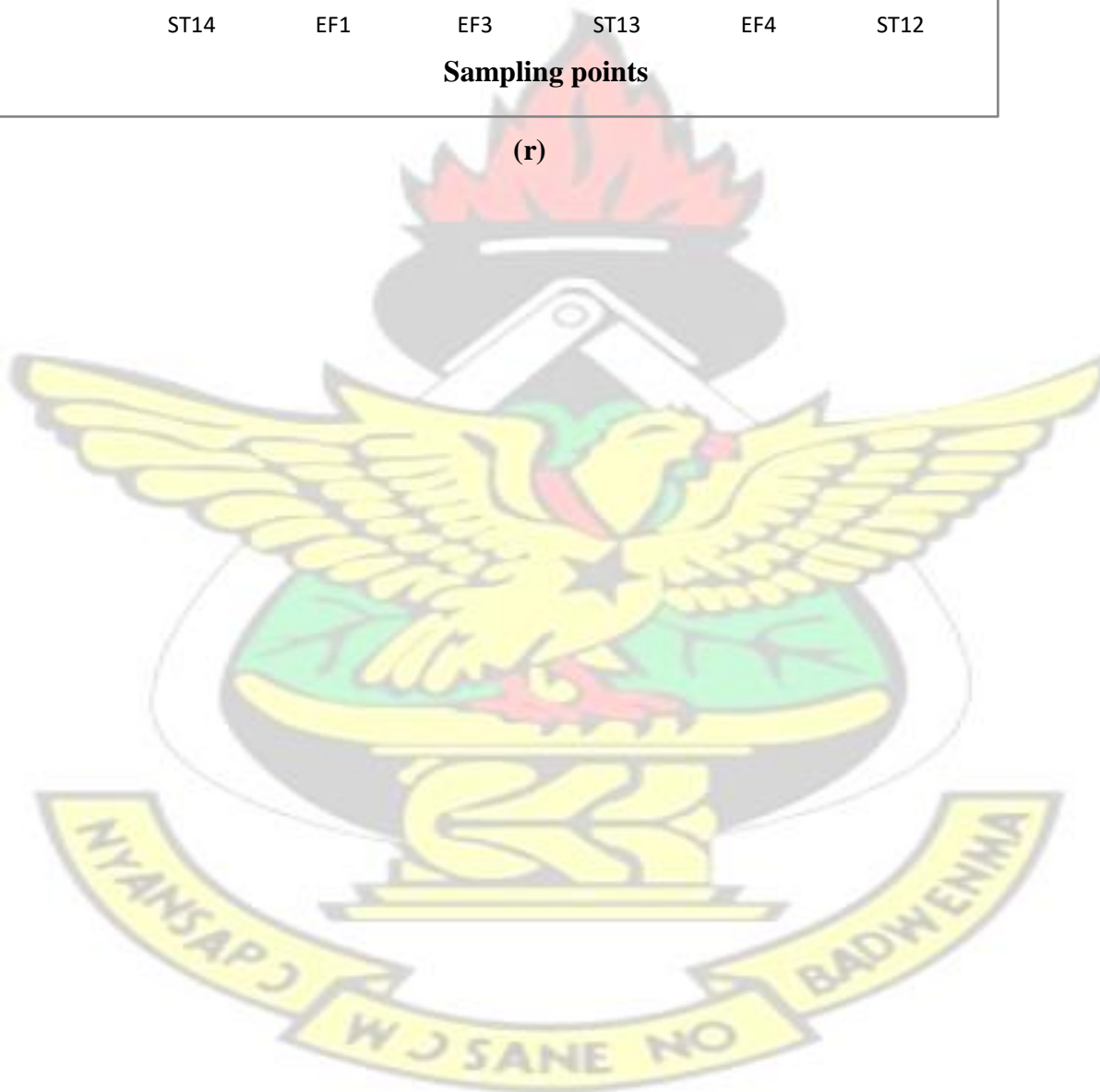
(p)



(q)



(r)



Appendix 6: Activities along the Stream and Site Pictures



Plate B: Stretch of the Onukpawahe stream



Plate C: Sampling point at Accra Abattoir choked with plastic waste



Plate D: Car washing bay along the stream at Community 18 sampling site



Plate E: Vegetable farm along the stream



Plate F: Pumps used for irrigation of vegetable farms along the stream



Plate G: Maize farm along the Stream



Plate H: Industrial effluent discharge point.



Plate I: Effluent discharge point



Plate J: Laboratory Analysis of nutrients.



Plate K: Analysis of Heavy metal by AAS

Appendix 7: EPA Effluent Quality Guidelines for Discharges into Natural Water and WRC Raw Water Quality Guidelines

Table 2.1A EPA Effluent Quality Guidelines for Discharges into Natural Water(EPA , 2012)

	PARAMETER/DESCRIPTION	PERMISSIBLE LEVEL
1.	pH	6 – 9
2.	Temperature	<3°C above ambient
3.	Colour (TCU)	100
4.	BOD (mg/l)	50
5.	COD (mg/l)	250
6.	Total Dissolved Solids (mg/l)	1000
7.	Total Suspended Solids (ppm)	50
8.	Turbidity (NTU)	75
9.	Conductivity (µS/cm)	1500
10.	Total Coliforms (MPN/100ml)	400
11.	Ammonia as N (mg/l)	1.0
12.	Nitrate (mg/l)	10
13.	Cadmium (mg/l)	<0.1
14.	Total chromium (mg/l)	0.5
15.	Copper (mg/l)	2.5
16.	Lead (mg/l)	0.1
17.	Zinc (mg/l)	5.0
18.	Chloride (mg/l)	250
19.	Sulphate (mg/l)	200
20.	Phosphate(mg/l)	2.0
21.	Total Coliforms(MPN/100ml)	400
22.	Faecal Coliforms(MPN/100ml)	400

Table 2.1B: WRC Raw Water Quality Guideline for Domestic Used (WRC, 2003).

	PARAMETER/DESCRIPTION	Target Water Quality Range
1.	pH	6 – 9
2.	Temperature	<2°C above ambient
3.	Colour (TCU)	0-15
4.	BOD (mg/l)	0-30
5.	COD (mg/l)	0-75
6.	Total Dissolved Solids (mg/l)	0-450
7.	Total Suspended Solids (mg/l)	0-5
8.	Turbidity (NTU)	0-5
9.	Conductivity (µS/cm)	0-70
10.	Total Coliforms (MPN/100ml)	0-5
11	Ammonia as N (mg/l)	1.0
12	Nitrate (mg/l)	0-6
13	Cadmium (mg/l)	0-0.1
14	Total chromium (mg/l)	0-0.5
15	Copper (mg/l)	0-3
16	Lead (mg/l)	0-0.1
17	Zinc (mg/l)	0-3.0
18	Chloride (mg/l)	250
19	Sulphate (mg/l)	200
20	Phosphate(mg/l)	2.0
23.	Total Coliforms(count/100)	0-5
24.	Faecal Coliforms(Count/100)	0

Appendix 8: Dissolved Oxygen Percent (%) Saturation Sheet

Temp (C)	D.O. (mg/L)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15*
0	7%	14%	21%	27%	34%	41%	48%	55%	62%	68%	75%	82%	89%	96%	103%
1	7%	14%	21%	28%	35%	42%	49%	56%	63%	70%	78%	85%	92%	99%	106%
2	7%	14%	22%	29%	36%	43%	51%	58%	65%	72%	80%	87%	94%	101%	109%
3	7%	15%	22%	30%	37%	45%	52%	60%	67%	74%	82%	89%	97%	104%	112%
4	8%	15%	23%	31%	38%	46%	53%	61%	69%	76%	84%	92%	99%	107%	115%
5	8%	16%	24%	31%	39%	47%	55%	63%	71%	78%	86%	94%	102%	110%	118%
6	8%	16%	24%	32%	40%	48%	56%	64%	72%	80%	88%	97%	105%	113%	121%
7	8%	17%	25%	33%	41%	50%	58%	66%	74%	83%	91%	99%	107%	116%	124%

